

MUDDY CREEK RESTORATION PARTNERSHIP

Final Project Report Section 319 Grant Project Number EW06043

**Submitted to the North Carolina Division of Water Quality
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**Report Developed for the Muddy Creek Restoration Partnership
by Equinox Environmental Consultation and Design, Inc.**

The Muddy Creek Restoration Partnership is comprised of:

McDowell County Soil and Water Conservation District, North Carolina Cooperative Extension Service, McDowell County, City of Marion, Burke County, Natural Resources Conservation Service, North Carolina Wildlife Resources Commission, Duke Energy Corporation, Trout Unlimited, Foothills Conservancy of North Carolina, Carolina Land and Lakes and Mountain Valleys Resource Conservation & Development Councils, and Equinox Environmental Consultation and Design, Inc.

Executive Summary

In the ten years beginning in 1998, stream improvement projects were completed on over 50,000 linear feet of stream in the Muddy Creek watershed, located in Burke and McDowell Counties, North Carolina. The Muddy Creek Restoration Partnership (MCRP) was granted \$141,000 by the North Carolina Division of Water Quality (NCDWQ) through the U.S. Environmental Protection Agency's (USEPA) Section 319 program to implement a three-year monitoring program in the watershed. This monitoring (Project #EW06043), covering the years 2005 – 2007, was intended to document potential site-specific and cumulative watershed scale changes resulting from stream improvement activities.

This final project report summarizes the data collected during the project. This document was developed by Equinox Environmental Consultation and Design, Inc. (Equinox), which serves as the technical consultant to the MCRP. The document is intended to accomplish three goals:

- Document data collection activities and data collected during the project;
- Present an overview of current stream conditions based upon the data collected; and
- Use the available data to evaluate the impacts of completed stream restoration projects.

1. Background

Muddy Creek drains a watershed of 111 square miles, entering the Catawba River just below Lake James. The MCRP was formed in 1998 out of a concern for sedimentation problems in the Muddy Creek watershed. Since that time the MCRP has worked to accomplish two main goals:

- 1) To improve water quality in the Muddy Creek watershed to the degree that it promotes a naturally reproducing tailrace trout fishery in the Catawba River below Lake James.
- 2) To improve water quality and aquatic habitat in the Muddy Creek watershed such that it achieves a use support designation of fully supporting for all water courses.

To date, the Partners have focused primarily on addressing stream bank erosion and riparian vegetation problems in the watershed, emphasizing three types of projects: natural channel design (NCD) restoration, livestock exclusion, and riparian revegetation. These are collectively referred to in this report as stream improvement or stream restoration projects.

2. Methods

In August 2005, the MCRP submitted a Quality Assurance Project Plan (QAPP) to NCDWQ outlining the monitoring program to be conducted under this grant, including activities to ensure data integrity. The QAPP was subsequently approved by NCDWQ and serves as the basis for all project data collection activities.

The project approach involved monitoring a large number of sites throughout the watershed. Given the watershed-wide interests of the MCRP, the Partners determined that it would be more useful to conduct broad-based monitoring, rather than to focus attention on a small number of locations. This has necessarily limited the intensity of sampling at individual sites.

Twenty-nine stations were monitored, representing three types of locations:

- Site impact monitoring stations - sites located within individual restoration project areas;
- Cumulative impact monitoring stations – sub-watershed and watershed scale sites;
- Comparison sites - small stream sites where no restoration activities were anticipated within the project period.

The primary indicators used included:

- Riffle substrate size distributions (pebble counts);
- Riffle embeddedness;
- Bank erosion potential (Bank Erosion Hazard Index);
- Overall aquatic habitat quality, using the N.C. Division of Water Quality (NCDWQ) stream habitat protocol;
- Bacterial contamination (fecal coliform concentration); and
- Benthic macroinvertebrate community condition, using the NCDWQ and Virginia Save Our Streams (VASOS) protocols.

Benthic macroinvertebrate monitoring using the NCDWQ standard qualitative method was carried out at four sites in July of 2005, 2006 and 2007 by Duke Energy personnel, who are certified by NCDWQ to perform this monitoring. Fecal coliform sampling was conducted by Duke Energy and Equinox staff. Fecal coliform water samples for 2005 and 2006 were analyzed at the Duke Bacteriological Laboratory, whereas samples for 2007 were analyzed at the laboratory of the Environmental Quality Institute at the University of N.C., Asheville. Both labs were certified by the NCDWQ to perform these analyses. During each year, a minimum of five water samples were collected within a 30-day period at each site.

All remaining data collection activities were conducted by Equinox. Monitoring was conducted during the summer and fall of each year. To provide additional information on variability in stream conditions, the annual monitoring was supplemented at six sites with quarterly monitoring conducted during the three remaining seasons.

A variety of existing data sources were used to supplement field data collection efforts. Among these were monitoring information from stream restoration design firms and available precipitation and stream discharge data.

3. Findings – General Stream Conditions

Precipitation and stream discharge declined progressively during the three-year monitoring period. The N.C. Drought Monitoring Advisory Council rated drought conditions in McDowell County as severe or worse during most of 2007.

The following broad conclusions regarding stream condition can be drawn from the data collection efforts during 2005-2007:

- Benthic community data collected by Duke Energy on North and South Muddy Creeks indicate a system under stress, with pollution tolerant organisms prominent. NCDWQ biological community data (benthos and fish), collected at different sites on these streams, indicate somewhat better conditions in most cases.

- The Duke and NCDWQ biological community data generally indicate that both North and South Muddy Creeks have improved between 2002 and 2007. The reasons for this improvement are not clear, although NCDWQ believes that lower nonpoint source inputs due to the drought may be responsible for improved conditions at some locations.
- Contamination from fecal coliform bacteria is a major concern. Violations of the State water quality standard for fecal coliform are widespread, occurring consistently at most sites during the three-year period.
- Impacts of sedimentation on riffle habitat occur widely throughout the watershed. Riffle embeddedness is moderate or worse at most sites, indicating substantial loss of this important habitat type.
- Substantial aquatic habitat degradation is evident at most sites, especially in the South Muddy Creek drainage.
- Moderate bank erosion potential is evident at most sub-watershed sites in the Muddy Creek watershed.
- Conductivity levels at most sites, especially in the North Muddy Creek drainage, are well above normal background levels and reflect pollutant inputs.

4. Findings – Restoration Effects

While extensive stream improvement activities have thus far been completed, these projects directly affect less than three percent of the channel network in the Muddy Creek watershed, addressing only nine percent of the reach length prioritized in the MCRP's 2003 watershed plan.

The current monitoring effort did not formally evaluate project implementation (e.g., by comparing observed conditions to documented conditions at the completion of construction, or by assessing structural stability). However, informal observation, as well as information available from funding agencies and design firms, suggests that projects are generally performing as intended.

Site Scale Effects.

Site-specific impacts were examined at seven reaches where stream improvement projects are complete and at three comparison reaches, chosen for the relative stability of site management over the study period as well as for the lack of known disturbance in their upstream drainages. The impacts observed can be summarized as follows:

- Improvement in overall aquatic habitat and in bank erosion potential was evident at all natural channel design sites for which both pre-restoration and post-restoration data were available.
- The comparison sites did not generally show improvement in these parameters, increasing the likelihood that results could be attributed to the restoration efforts and not to other factors.
- Improvement in substrate parameters due to project activity was generally not evident at natural channel design sites. Depending upon the location, either improving trends were not yet evident, or there was some doubt, given site-specific circumstances, that improvement could be reasonably attributed to the stream project.
- Improvements in benthic community conditions were not evident at any site. At a number of natural channel design sites, a decline that can likely be attributed to construction-

related disturbance is evident. In some cases, benthos have begun to rebound from this impact, but still had not yet recovered to the pre-project condition by the end of the monitoring period. The deepening drought in the last few years of the monitoring project is thought to be a serious complicating factor.

- Photographic evidence indicates clear improvements in stream morphology, bank stability and other characteristics at NCD sites.
- Less change is evident at the sites where improvement activities involved only livestock exclusion or riparian area revegetation. Improved stream condition at such sites is highly dependent on vegetative growth and longer-term natural processes to heal stream bank erosion and enhance habitat.

Broader Scale Effects.

Drawing conclusions regarding the impact of restoration activities becomes progressively more difficult as scale broadens, because the number of confounding factors increases and the task of accounting for these factors becomes more complex. For this reason the broader scale analysis concentrated on sub-watersheds draining limited areas, where the likelihood of drawing defensible conclusions about stream conditions was greatest.

Estimates of sediment inputs from bank erosion indicate that the natural channel design projects completed to date have reduced sediment inputs to Muddy Creek and its tributaries by at least 6,000 tons per year. This is the equivalent of 375 dump truck loads of sediment per year, assuming a 16 ton capacity for a typical 3-axle dump truck. This figure does not include estimates of sediment reductions from the more than 15,000 linear feet of stream where only livestock exclusion and/or revegetation activities occurred.

Despite reductions in bank erosion at restoration project sites, in-stream improvement at the sub-watershed and watershed scales is not yet evident. This is not surprising given the recent completion of most restoration projects and the large restoration need remaining.

5. Discussion and Recommendations

Over the 10 years between 1998 and 2008, stream improvement projects were completed on 50,200 feet of stream in the Muddy Creek watershed. About two thirds of this length has involved natural channel design (NCD) stream restoration, with the remainder some combination of livestock exclusion and riparian revegetation projects. Three-quarters of this work has been completed within the past three years. This is a considerable accomplishment, representing the substantial work and commitment of the organizations making up the MCRP, as well as the contributions of many funding agencies and local property owners.

The three-year monitoring project discussed in this document represents the efforts of the MCRP to evaluate the impact of these restoration activities. While this report marks the end of the monitoring project, the MCRP continues to work actively in the watershed. The MCRP has been the catalyst for nine ongoing projects, representing over 30,000 linear feet of stream work, in the design or construction phase. Furthermore, because of the planning work conducted by the MCRP and the effectiveness of the MCRP in initiating on the ground restoration, the North Carolina Ecosystem Enhancement Program (NCEEP) has designated Muddy Creek as a Priority

Watershed for implementing stream and wetland mitigation projects. Under contract to NCEEP, Equinox has recently completed a landowner outreach effort that identified approximately 34,000 feet of potential NCD restoration projects in the watershed.

The vision of the MCRP is ultimately for improved ecological conditions, including aquatic habitat and biological communities, in Muddy Creek and its tributaries, as well as in the Catawba River below its confluence with Muddy Creek. The partnership seeks to improve water quality and habitat such that a more natural sediment regime is established, all streams in the watershed support their intended uses, and pollution from Muddy Creek no longer serves as a stressor to the trout population in the Catawba River.

The partnership's activities are not limited to the types of stream improvement projects discussed in this report. The group is spearheading a watershed planning project for Corpening Creek/Youngs Fork, which is considered impaired by the NCDWQ due to toxic pollutants and other stressors. The plan will identify the sources of the pollutants and make recommendations to improve water quality. Funded by the North Carolina Clean Water Management Trust Fund and the USEPA Section 319 Program, this effort will be completed in 2009.

Discussion.

Implementation of stream improvement projects on Muddy Creek and its tributaries is still a work in progress, and the same can be said for efforts to evaluate the effects of those projects. The planning and implementation of stream restoration projects in the watershed is proceeding at a rapid pace, assuring that many sediment inputs from stream bank sources will continue to be addressed. However, a number of issues merit additional attention:

1. Further documentation of the effects of restoration projects;
2. Review of the sediment problems in a broader context, including sediment sources other than bank erosion;
3. Addressing fecal coliform bacteria contamination.

Documentation of Restoration Effects.

While the findings reported in this document indicate a number of positive outcomes from the stream improvement efforts completed to date, including the prevention of approximately 6,000 tons of sediment inputs per year, additional work remains in order to adequately quantify the effects of these projects. For example, most restoration projects in the watershed have been completed only recently. Due to the time lag in sediment transport, it is very likely that much of the sediment reduction at the project site level is not yet reflected by conditions further downstream. Additionally, some site improvements, such as those dependent upon vegetative growth, did not have sufficient time to fully develop.

A number of other limitations are inherent in the approach used in this project:

- Sediment transport was not measured directly.
- Monitoring at most sites was limited to a series of three annual observations, which is insufficient to clearly identify trends in parameters subject to wide fluctuations.
- Information on watershed activities and land use change during the monitoring period was not systematically collected, providing little information to aid the understanding of changes in stream condition at the sub-watershed and watershed scales. While fairly

recent information on land cover change was available, it did not cover the monitoring period.

Finally, it is clear that the MCRP has established considerable momentum in implementing stream restoration projects, and the extent of restoration work carried out in the near future will be substantial. Within five years, the length of completed projects is likely to be more than double what it is today.

All of these factors point to the need for additional monitoring to track the impacts of stream improvement activities over at least the next decade. The early NCD projects in the watershed were funded through a variety of mechanisms, most of which required limited, if any, post-project monitoring. However, most current and future NCD projects are likely to be funded by the NCEEP, which currently requires annual monitoring using a standardized methodology over a five-year post-project period. The MCRP resources will be best used by building on this effort, and focusing primarily on monitoring of watershed and sub-watershed scale impacts. Livestock exclusion and revegetation projects are a possible exception, as little documentation is generally available for such projects.

Sediment Transport and Sources.

While the MCRP has focused considerable attention on documenting sediment reductions, and other improvements related to the stream projects implemented, it is important not to lose sight of the bigger picture. Visual assessment and historic total suspended solids sampling provide a strong indication that sediment loads have been very high. However, overall sediment loads have not been accurately determined, nor have the full range of potential sources been evaluated.

A computer simulation model, referred to as WARMF (Watershed Analysis Risk Management Framework), was developed for the watershed by Systech Engineering, in conjunction with Duke Energy and the Electric Power Research Institute. This model predicted suspended sediment loads from the Muddy Creek watershed of 1,435,000 kg/day, or over 577,000 tons per year. The assumptions used in model development are difficult to evaluate, however, and the accuracy of the resulting estimates is not clear. An earlier appraisal tentatively estimated the sediment load at about 20,000 tons per year. This estimate was based upon the limited information available in the 1990s, and is likely too low. Neither of the available estimates attempted to account for bedload transport, which may be considerable in this watershed.

Stream bank erosion is clearly an important sediment source in the watershed. However, the MCRP has thus far focused little attention on sediment contributions from upland areas. Potential upland sources include improperly managed forestry and agricultural operations, eroding roads, land clearing for development, and unstabilized portions of existing developed areas. Whether their magnitude is increasing or decreasing is not known. Since increased loading from upland areas could offset any reductions from stream improvement projects, this is an important issue.

At this point there are a number of important questions that cannot be answered:

- Have overall sediment loads from the watershed been increasing or decreasing?

- If stream restoration projects are successful, how long might it take before loads to the Catawba River are substantially reduced?
- Will increases in upland inputs offset sediment reductions from stream bank sources?

Drought conditions in western North Carolina, including McDowell County, progressively worsened during the monitoring period. This very likely limited sediment transport in the Muddy Creek watershed and complicates the interpretation of results.

Data on trends in the status of biological communities in North and South Muddy Creeks are ambiguous. Monitoring by NCDWQ indicates some improvement from 2002 to 2007, though the agency suspects some of this may be due to the recent low precipitation and streamflows (with resultant lower inputs of nonpoint source pollutants). Benthic community monitoring conducted by Duke indicates improved conditions in 2005-2007 compared to 2001-2004, but not compared to 2000.

Fecal Coliform Bacteria.

The monitoring conducted during this study has documented that contamination from fecal coliform bacteria is significant and widespread. Bacterial contamination is not an ecological concern for Muddy Creek and the Catawba River (this contamination does not directly impact aquatic organisms), although it is possible that nutrients and oxygen-consuming waste that enters streams along with the bacteria could be problematic. However, the frequent violations of the North Carolina water quality standard for fecal coliform are clearly a public health concern that should be addressed.

The current study was not designed to provide information on the source of this contamination, and little such information is available. Livestock waste is the likely source at some locations, though livestock access to streams has been greatly reduced or eliminated in many areas through the efforts of agricultural agencies and the MCRP. Straight-piping or other sources of domestic waste are another possible source, although no systematic assessment of the magnitude of this problem has been made. Wildlife and domestic animals are other potential sources.

Recommendations.

The MCRP recognizes that watershed improvement is an iterative process involving multiple cycles of planning and assessment, implementation of management measures and evaluation of outcomes. The following recommendations are made to address the issues discussed above.

Documentation of Restoration Effects.

- The MCRP should seek to establish a long-term monitoring effort to evaluate conditions in North and South Muddy Creeks related to sediment impacts. If resources allow, this effort should be extended to selected sub-watersheds.
 - Monitoring stations should be established at the lower end of North and South Muddy Creeks, near the confluence of those streams.
 - Physical monitoring should focus on parameters likely to be sensitive to changes in sediment supply, including substrate size distribution and aquatic habitat.
 - Physical monitoring should be conducted every three years over a fifteen-year period, for a total of six monitoring events. It is likely that numerous restoration

projects will be implemented over the next five to ten years. Because of this, as well as the time lag between project implementation and downstream improvements, a long monitoring period is essential.

- If resources allow, consideration should be given to the collection of suspended sediment samples using single stage samplers, supplemented by manual collection of grab samples during selected storm events. While grab samples will not generally provide an accurate measurement of overall suspended sediment concentrations, over time they could potentially provide an indication of whether concentrations are increasing or decreasing.
- If suspended sediment sampling is conducted, stage recorders should be installed at the monitoring sites to allow estimation of stream discharge and development of stage-discharge relationships. Stage recorders would also facilitate documentation of the time of sample collection (for single stage samplers).
- Future evaluations of NCD site impacts should build on the required monitoring being conducted for NCEEP projects. Post-project data will eventually be available for these locations. After reviewing the data available from the NCEEP monitoring, the MCRP should determine whether additional data collection is warranted at selected sites to fill any information gaps that remain.
- Since projects that involve only livestock exclusion or revegetation are generally not evaluated by funding agencies, it would be beneficial for the MCRP to obtain funding that would allow it to collect some pre- and post-project information for selected project sites.

Sediment Transport and Sources.

- Areas in need of channel restoration, revegetation or livestock exclusion were evaluated in 2000 and 2001 for inclusion in the Muddy Creek watershed plan. It is time for a reappraisal of those priorities. The MCRP should review the original assessment data in light of stream improvement work completed or anticipated and reestablish priorities, undertaking additional field data collection and GIS assessment if necessary.
- Little information is available on the extent of sediment inputs from upland areas and whether those sources have been increasing or decreasing. The MCRP should conduct an assessment of upland sediment inputs to address both of these issues. The source areas covered by this assessment should include sites undergoing active land disturbance, existing developed areas, agricultural land, and silvicultural operations.
- Periodically updated land cover data will be a useful component of the two recommendations immediately above. Land cover data should be updated approximately every five years.
- While a robust estimate of overall sediment transport in the Muddy Creek watershed could be useful, the technical complexity and expense of the monitoring effort necessary to construct such an estimate is beyond the scope of activity that the MCRP can undertake at the present time. The MCRP should instead focus its monitoring resources on documenting stream conditions, especially as they relate to the implementation of stream improvement projects.

Fecal Coliform Bacteria.

- The MCRP should share data on fecal coliform bacteria standards violations with NCDWQ and encourage the agency to include the affected streams on the 303(d) list (impaired waters list).
- The MCRP should work with local governmental agencies and the NCDWQ to identify sources of fecal coliform and should cooperate with NCDWQ in developing a TMDL (total maximum daily load) and restoration plan.

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Section 1 Introduction

The Muddy Creek Restoration Partnership (MCRP) was granted \$141,000 by the North Carolina Division of Water Quality (NCDWQ) through the U.S. Environmental Protection Agency's (USEPA) Section 319 program to implement a three-year monitoring program in the Muddy Creek watershed (Project #EW06043). This monitoring was intended to document potential site-specific and cumulative watershed scale changes resulting from the implementation of stream improvement projects in the watershed. Data collection was carried out during 2005, 2006 and 2007.

This final project report summarizes the monitoring data collected during the three years of the project. This document was developed by Equinox Environmental Consultation and Design, Inc. (Equinox), which serves as the technical consultant to the MCRP. The project was conducted with input and review from the MCRP's Technical Committee (see Appendix A for list of members). Preliminary analyses of the first and second year monitoring data were presented in previous reports (MCRP, 2006 and 2007a).

1.1 Background

Muddy Creek, located primarily in Burke and McDowell Counties, flows into the Catawba River just below Lake James (Figure 1.1). The 111 square mile watershed consists of the North Muddy Creek drainage (56 square miles), the South Muddy Creek drainage (40 square miles), and 15 square miles draining to the mainstem of Muddy Creek.

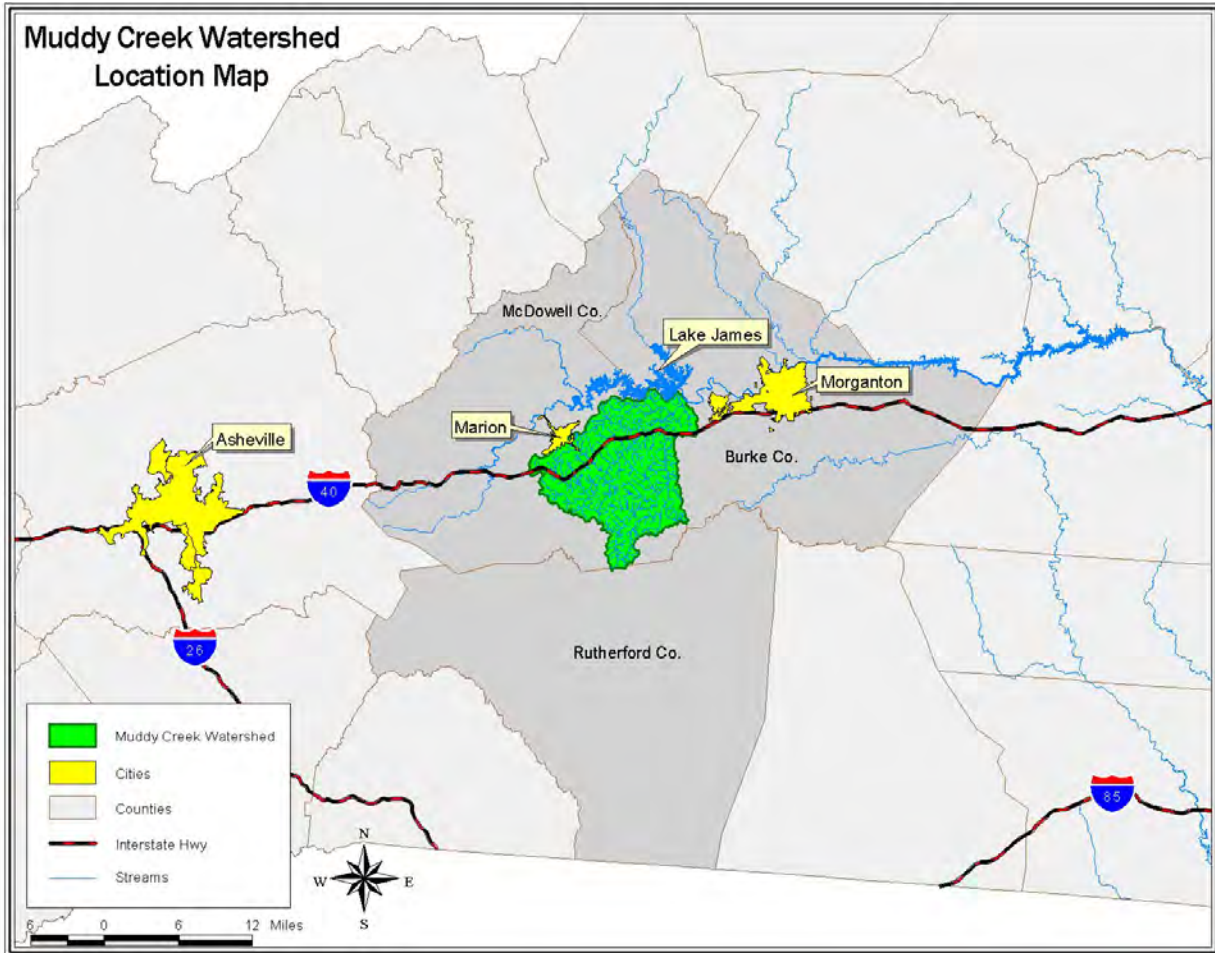
The Muddy Creek Restoration Partnership was formed in 1998 out of a concern for sedimentation problems in the Muddy Creek watershed, which were believed to be compromising aquatic habitat, as well as serving as a stressor on the tailrace trout fishery in the Catawba River below Lake James. Muddy Creek and surrounding streams are too warm for trout. However, coldwater releases from Lake James provide conditions suitable for trout to survive in the Catawba River below the dam. Muddy Creek is the largest tributary to the Catawba River in this area.

Initial field assessments and GIS analyses conducted by the MCRP, documented in the *Feasibility Report and Restoration Plan for the Muddy Creek Watershed* (MCRP, 2003), provided confirmation of widespread sediment and habitat problems in the watershed. This work documented elevated suspended solids concentrations, degraded habitat due to sedimentation in riffles and pools, severe channel entrenchment and bank erosion, and limited woody riparian vegetation along many stream reaches.

The MCRP has been working to accomplish two main goals:

- 1) To improve water quality in the Muddy Creek watershed to the degree that it promotes a naturally reproducing tailrace trout fishery in the Catawba River below Lake James.
- 2) To improve water quality and aquatic habitat in the Muddy Creek watershed such that it achieves a fully supporting use designation for all water courses.

Figure 1.1. Location of the Muddy Creek Watershed in McDowell and Burke Counties, North Carolina



To date, the Partners have focused primarily on identifying projects addressing stream bank erosion and riparian vegetation problems in the watershed. These include stream channel restoration, livestock exclusion, and riparian revegetation activities. These are collectively referred to in this report as stream improvement or stream restoration projects. The primary motivation of these projects, from the MCRP perspective, was to reduce sediment inputs and downstream impacts of sedimentation. Improving biological communities and water quality was a secondary goal.

The Partnership is committed to a long-term process of watershed improvement and evaluation. Although the initial watershed plan (MCRP, 2003) provided the foundation for early stream improvement activities, the need for further monitoring soon became apparent. Given the size and complexity of the watershed, it is critical to ongoing planning efforts that the MCRP understand both the site specific impacts of individual restoration efforts and the cumulative effects of multiple improvement projects at broader scales. In 2004, the MCRP sought funding from the USEPA Section 319 Program to undertake a three-year monitoring effort to address these information needs for the 2005-2007 period. Monitoring results also will be of value to others interested in large scale watershed restoration efforts.

1.2 Purpose and Organization of Report

This final report is intended to accomplish three goals:

- Document data collection activities and data collected during the project;
- Present an overview of current stream conditions in the watershed based upon the data collected; and
- Use the available data to evaluate the impacts of completed stream restoration projects.

This document is organized as follows:

- The remainder of Section 1 presents an overview of the monitoring approach used and data collection activities conducted;
- Section 2 summarizes pertinent watershed characteristics, including land cover trends, meteorological information and stream discharge;
- Section 3 presents an overview of stream conditions and water quality in the Muddy Creek watershed;
- Section 4 discusses the types of stream improvement projects implemented by the MCRP and reviews the status of completed projects;
- Section 5 provides an evaluation of restoration impacts, including both site specific impacts and broader scale effects;
- Section 6 presents a discussion of the project findings and offers recommendations for future MCRP action.

1.3 Overview of Monitoring Design

1.3.1 Objectives and Approach

The current monitoring project was undertaken to:

- Evaluate the site-specific impacts of stream improvement activities completed to date in the watershed;
- Evaluate the cumulative impacts of completed projects at sub-watershed and watershed scales; and
- Provide baseline data for the evaluation of future restoration efforts.

There are a variety of ways to approach monitoring design for this project. One approach is to focus concentrated attention on a small number of sites. This approach allows for an intensive investigation at each location, although the sites studied would not provide broad coverage of the entire watershed and may not be representative. Given the watershed-wide interests of the MCRP, both in evaluating restoration and in ongoing planning, the MCRP determined that the organization's needs would be better served at this point by implementing a broad-based monitoring approach, utilizing a large number of stations across the watershed. Of necessity, this limited the intensity of effort at any individual site.

Post-project evaluations can be undertaken for numerous reasons, including improving the science and practice of restoration design (Kondolf, 1995; Downs and Kondolf, 2002). The current monitoring project assesses in-stream condition in and downstream of restoration sites.

However, it does not formally evaluate the implementation of specific restoration projects in the sense that it does not compare pre-existing conditions to project design or post- construction conditions, and does not assess the stability of specific structures. Some stream improvement projects are being evaluated by the funding agencies, most notably the N.C. Ecosystem Enhancement Program (NCEEP), as part of regulatory permit requirements. The MCRP are not duplicating these efforts, but the results of such monitoring are integrated into the present document to the degree possible.

While one of the goals of the MCRP is to promote a self-sustaining tailrace trout population in the Catawba River immediately below Lake James, this project does not attempt to directly assess the status of that fishery resource. The fishery resource is affected by a wide variety of factors other than inputs from Muddy Creek, among them the status of water releases from Lake James, the extent of fishing pressure and various management policies. A study attempting to account for all of these factors is beyond the scope of this project, which focuses primarily on the Muddy Creek watershed itself.

In August 2005, the MCRP submitted to NCDWQ a Quality Assurance Project Plan (QAPP) outlining the monitoring program to be conducted under the Section 319 grant, including activities to ensure data integrity (MCRP, 2005 and 2007b). An amendment was submitted in February 2007 to allow for quarterly monitoring at selected sites. The QAPP was subsequently given formal approval by NCDWQ in April 2008.

1.3.2 Monitoring Stations

The project concept, as funded by the Section 319 grant and documented in the QAPP (MCRP, 2005), was to monitor a large number of sites throughout the watershed. Twenty-nine monitoring stations were included in the monitoring plan, representing three types of monitoring locations (Table 1.1 and Figure 1.2):

- **Site specific impact monitoring stations.** These are sites at which measurements are taken within individual restoration project areas (stream reaches where improvement projects have been implemented or are planned). These stations are generally, though not always, located on smaller (first to third order) streams. Since restoration project activities are implemented on varying schedules, the amount of pre- and post-construction data will differ by site.
- **Cumulative impact monitoring stations.** These are sites at which measurements are taken downstream of multiple restoration projects that have been completed, are under construction, or are planned. These stations represent 13 of the 14 sub-watersheds in the Muddy Creek watershed (Table 1.2 and Figure 1.1) and several broader scale areas.
- **Comparison sites.** These are small streams where no restoration activities were anticipated within the project period, and where major changes in upstream activities were considered unlikely.

Table 1.1. Summary of Data Collected from the Muddy Creek Watershed, 2005-2007

Station ID	Stream Name	Road Name	Drainage Area (mi ²)	Annual Monitoring			Quarterly Monitoring
				Benthos-(Duke)	Fecal Coliform-(Duke / Equinox)	Habitat, Physical Indicators and Benthos (Equinox) ¹	Selected Indicators (Equinox) ²
<i>Site-Specific Impact Stations</i> ³							
07	Patten Branch	Muddy Creek Road	2.1			X	
09	Hoppers Creek	Dysartsville Road	9.3		X	X	
10	South Fork Creek	SR 1776	1.3	X		X	
12	South Muddy Ck.	Sain Road	18.7		X	X	
17	UT to N. Muddy Ck.	Gilbert Byrd Road	0.1			X	
18	Thompsons Fork	South Creek Road	7.6			X	
20	Big Camp Creek	Burma Road	2.6			X	
21	Bledsoe Branch	Deacon Road	0.7			X	
27	Goose Creek	Huntsville Road	9.1			X	
28	UT to Goose Ck.	SR 1785	0.4			X	
<i>Cumulative Impact Stations</i> ³							
01	Catawba River	Powerhouse Road	499			X	
02	Catawba River	Conley Bumgarner Rd	502			X	
03	Catawba River	Watermill Road	506			X	
04	Old Catawba River	Bridgewater Road	6.9			X	
05	Muddy Creek	Hwy US 70	98.0			X	
06	South Muddy Ck.	Gilbert Byrd Road	39.7	X	X	X	X
08	South Muddy Ck.	Muddy Creek Road	33.5			X	
13	South Muddy Ck.	Hwy NC 226	12.9			X	X
19	North Muddy Ck.	Burma Road	42.8			X	X
22	Youngs Fork	Hwy NC 226	7.4		X	X	
24	North Muddy	Marlowe Road	24.6			X	
26	Goose Creek	Old Glenwood Road	9.3		X		
29	North Muddy Ck.	Old Glenwood Road	10.7		X	X	
16	North Muddy Ck.	Gilbert Byrd Road	56.3	X	X	X	X
25	Bobs Creek	Marlowe Road	2.1	X	X	X	X
<i>Comparison Stations</i> ³							
11	South Fork Creek	Landis Lane	0.5			X	
14	High Shoals Creek	Vein Mountain Rd	2.5			X	
15	UT to S. Muddy Ck.	Brackett Town Road	0.5			X	X
23	Jacktown Creek	Hwy NC 226	1.3		X ⁴	X	

(1) Primary indicators monitored annually included aquatic habitat, BEHI, substrate size (pebble count), embeddedness and VASOS benthic protocol (for all sites except those on the Catawba River). Secondary indicators include water quality field parameters, channel cross-sectional parameters and exotic invasive plant species.

(2) Indicators monitored quarterly included: substrate size (pebble count), embeddedness; BEHI, aquatic habitat quality (NCDWQ stream habitat protocol), VASOS and water quality field parameters

(3) Site classification based on QAPP. See Section 4 for current status.

(4) Monitoring of fecal coliform bacteria at this site was not part of the original monitoring plan, but was conducted during 2006 only, in order to provide planning information.

Figure 1.2. Project Monitoring Stations in the Muddy Creek Watershed

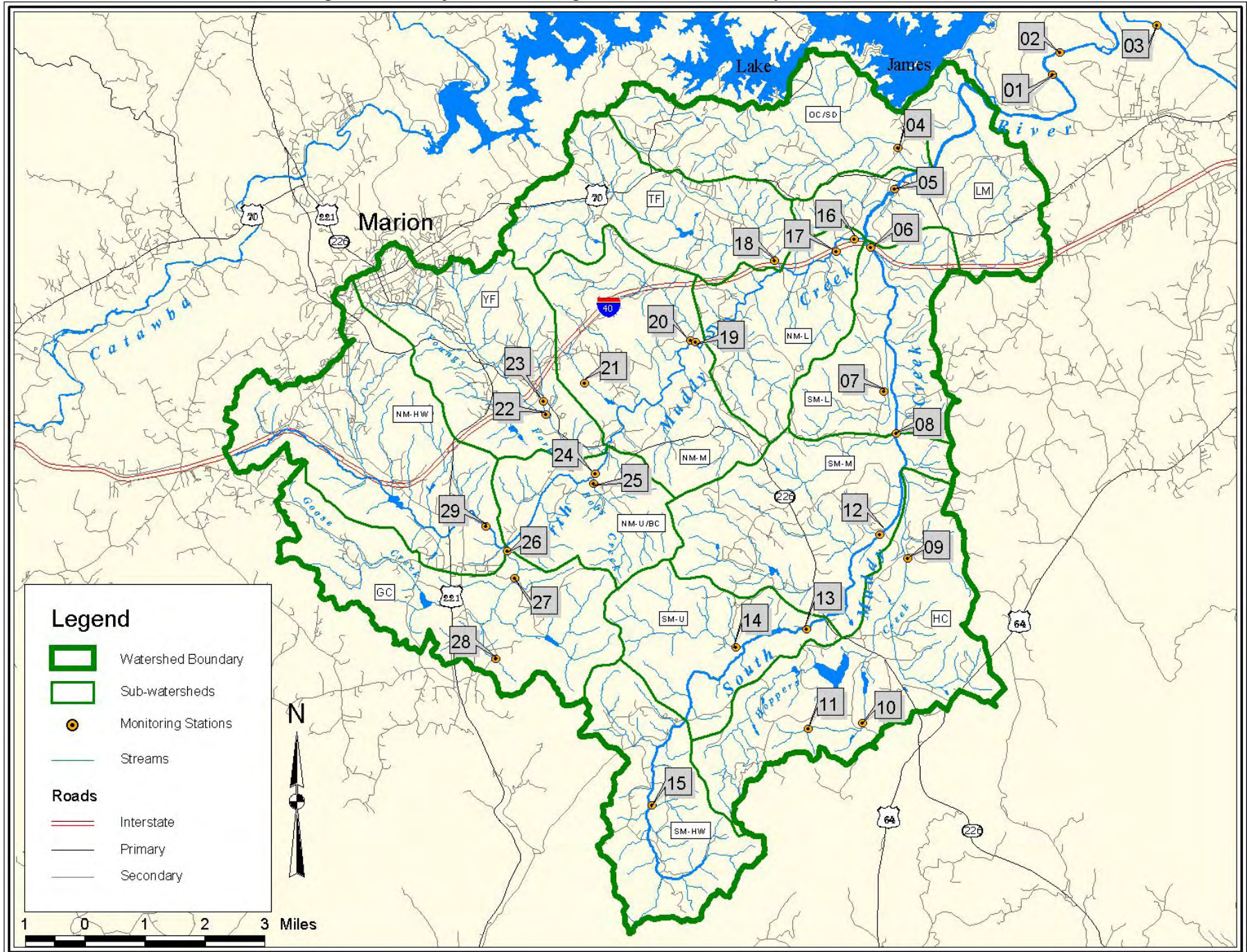


Table 1.2. Sub-Watersheds Delineated in the Muddy Creek Watershed

Sub-Watershed ID		Sub-Watershed Name
North Muddy Ck. Drainage	NM-HW	North Muddy-Headwaters
	GC	Goose Creek
	NM-U/BC	North Muddy-Upper/Bobs Ck.
	YF	Youngs Fork
	NM-M	North Muddy-Middle
	TF	Thompsons Fork
	NM-L	North Muddy-Lower
South Muddy Ck. Drainage	SM-HW	South Muddy-Headwaters
	SM-U	South Muddy-Upper
	HC	Hoppers Creek
	SM-M	South Muddy-Middle
	SM-L	South Muddy-Lower
Lower Muddy Ck. Drainage	LM	Lower Muddy Creek
	OC/SD	Old Catawba River/Shadrick Ck.

1.3.3 Indicators

Restoration activities can potentially have an impact on many components of stream ecosystems. To characterize these impacts, a variety of indicator measures was considered for this study, including: fish community integrity, benthic macroinvertebrate community integrity, sediment transport, sediment impacts, habitat quality and bacterial contamination. Indicator selection is discussed in detail in the QAPP (MCRP, 2005), and key issues are summarized below.

Physical indicators. Since reducing sediment input is a major objective of the stream improvement projects undertaken by the MCRP, direct measures of sediment transport (bedload and suspended sediment) would be useful. Since both bedload and suspended sediment move primarily during storm events or spates, accurate measurement of sediment transport requires sampling during high flow conditions. Many sediment impacts in the watershed are likely due to coarse material moving as bedload. However, bedload monitoring (Edwards and Glysson, 1999), which requires specialized equipment and is extremely labor intensive, was clearly beyond the scope of project resources.

Suspended sediment sampling was considered when the monitoring plan was developed. Accepted suspended sediment sampling methods (Edwards and Glysson, 1999) are also resource intensive and considered beyond the scope of the project. While simple grab sampling approaches are not likely to accurately characterize suspended sediment concentrations or loads, collection of baseflow suspended sediment samples was considered in order to provide some information on sediment concentrations. Between 1995 and 2001, over 400 baseflow total

suspended solids samples were collected by Duke Energy in the Muddy Creek watershed (Equinox, 2007). Most of these had concentrations below 10 mg/L, many below detection, and very few were above 30 mg/L. Based on these results, it seemed rather unlikely that changes in baseflow concentrations due to stream improvement projects could be readily detected. Baseflow sampling of suspended sediment was not considered to be a cost effective use of project resources.

The project relied instead on indicators of sediment impact and aquatic habitat quality. Indicators of the extent of sediment impact are much less resource intensive than direct measures of sediment transport and for this reason are more widely used. In general, one would expect these measures to be sensitive to the changes brought about by the types of stream improvement projects implemented in the Muddy Creek watershed. The following suite of four primary physical indicators was used:

- The BEHI, or Bank Erosion Hazard Index (Rosgen 1996 and 2001), is the stream bank erosion indicator most widely used in North Carolina. The BEHI involves the calculation of five metrics based on visual observation and measurement of bank height, bank angle and other parameters. The indicators are used to calculate a score ranging from 5 (lowest erosion potential) to 50 (highest), and the scores are classified into erosion potential classes as follows: very low (5-9.9), low (10.0-19.9), moderate (20.0-29.9), high (30.0-39.9), very high (40.0-45.9) and extreme (46.0-50).
- The NCDWQ stream habitat protocol for piedmont and mountain streams (NCDWQ, 2003) is a widely used measure of overall aquatic habitat quality. This protocol rates the overall aquatic habitat of a reach by adding the scores of eight habitat factors relevant to fish and macroinvertebrates. Total scores may range from zero (worst) to 100 (best).
- Substrate composition is an additional indicator of habitat quality (Gordon et al, 1992) and sediment transport dynamics that would be expected to be sensitive to stream improvement efforts. The pebble count method (Wolman, 1954) was used in this project to measure substrate composition. The technique involves the random selection of particles ('pebbles') from the surface of the stream bed and measurement of the intermediate axis of each particle.
- Sediment impacts on riffle habitat were assessed by estimating riffle embeddedness, the extent to which larger riffle substrate is covered by finer sediments.

Biological indicators. The condition of the benthic macroinvertebrate community is an excellent indicator of overall stream quality, and is an integral part of the NCDWQ statewide monitoring program. Benthic community monitoring using the NCDWQ standard qualitative method (NCDWQ, 2003) was utilized at four sites (Table 1.1). Resource limitations prevented more widespread use of NCDWQ methods. The modified Virginia Save Our Streams (VASOS) rocky bottom benthic monitoring method (VASOS, 2007), which is less resource intensive, was utilized on all sites except those on the Catawba River.

The VASOS method differs from the NCDWQ standard qualitative method in a number of respects, including the level of taxonomic identification used (NCDWQ methods are more detailed) as well as the habitats sampled. VASOS monitoring is limited to sampling of a single riffle in a reach, whereas the standard qualitative methods includes two riffle samples as well as samples of a number of other habitat areas. The modified VASOS method has been found to

yield conclusions about ecological conditions that are very similar to those provided by some more resource intensive methods (Engel and Voshell, 2002), although the protocol has not been specifically benchmarked against NCDWQ methods. Although initially developed for western Virginia, the method has been applied elsewhere in the southern Appalachians.

Fish community monitoring (specifically the N.C. Index of Biological Integrity method used by NCDWQ) is one potential tool for assessing overall water quality conditions in the Muddy Creek watershed. Fish community monitoring was not conducted due to resource limitations and because of concerns that, given the current status of the fish community in the Muddy Creek watershed, the NCIBI may not be highly sensitive to habitat and water quality changes resulting from restoration activities (MCRP, 2005).

Bacterial contamination. Fecal coliform bacteria monitoring was conducted at selected sites. Reducing bacterial contamination is not the major focus of restoration efforts, although livestock access to streams in the watershed is a problem, and a number of livestock exclusion projects have been implemented. While sediment and bacterial inputs can be linked, bacterial contamination is included in this project not primarily to evaluate restoration impacts, but to provide additional water quality data for watershed assessment purposes. Fecal coliform is the most widely used and cost effective indicator of bacterial contamination. The prescribed fecal coliform monitoring approach for comparing ambient conditions to the state standard requires that a minimum of five samples be collected within a 30-day period. Due to resource limitations, fecal coliform monitoring was limited to eight stations, chosen to provide coverage of selected sub-watersheds (Table 1.1).

Secondary indicators. Data were also collected on several secondary indicators for descriptive purposes and to support ongoing planning efforts. Secondary indicators include water quality field parameters (dissolved oxygen, specific conductance and temperature), channel cross-sectional parameters and presence of exotic invasive plant species in the riparian zone. See the QAPP for additional information (MCRP, 2005).

1.4 Summary of Monitoring Activities Conducted

In order to adhere to the contract schedule, capitalize upon matching in-kind services that were available, and collect first year data prior to restoration work at site impact data stations, the MCRP began collecting the first year's data in the summer of 2005 following the monitoring design and QA/QC stipulations described in the QAPP.

Benthic macroinvertebrate monitoring using the NCDWQ standard qualitative method was carried out at four sites in July of 2005, 2006 and 2007 by Duke Energy personnel certified by NCDWQ to perform this monitoring. Organisms were picked in the field and transported to the Duke laboratory for identification.

Fecal coliform sampling was conducted in September 2005 and August 2006 by Duke Energy and Equinox staff, and in September-October 2007 by Equinox. Samples for 2005 and 2006 were analyzed at the Duke Bacteriological Laboratory using the most probable number method, estimated via the multiple tube technique. Samples for 2007 were analyzed at the laboratory of

the Environmental Quality Institute at the University of N.C., Asheville using the membrane filter procedure. Both labs were certified by the NCDWQ to perform these analyses. A minimum of five samples were collected annually at each site within a 30-day period each year. Samples were collected, iced and transported to the lab within the six-hour holding time, as specified in the approved QAPP.

All remaining project activities were conducted by Equinox. Annual monitoring at all sites was conducted during the summer and fall of each year. To provide additional information on variability in stream conditions, the annual monitoring was supplemented at six sites with quarterly monitoring conducted during the three remaining seasons. Resources precluded collecting seasonal data at all locations.

A 100-yard reach was delineated at each site for collection of physical data. The habitat assessment was conducted on the entire reach. Pebble count, embeddedness, BEHI and VASOS monitoring were carried out at riffles judged to be representative of the reach. In some cases additional pebble counts were conducted in representative pool areas. Reach boundaries were identified in the field via global positioning system units (GPS), field markers and landmarks. Riffle transects and other monitoring locations were identified via GPS and position on a tape stretched along the channel.

An effort was made to monitor the same transects each year, though in some cases transects were moved due to riffle migration and unanticipated events such as beaver impoundments. Where a channel was modified or newly constructed at a site due to restoration activities during the monitoring period, it was impossible to conduct subsequent assessments at the original transect. Representative locations within the newly constructed reach were selected for monitoring.

All monitoring activities were conducted according to the sampling plan, field protocols, laboratory protocols and QA/QC procedures specified in the QAPP (MCRP 2005 and 2007b). The only exception was where unavoidable circumstances prevented the collection of data on particular indicators, for example when the embeddedness and VASOS protocols could not be carried out because riffle areas were not present, or where water quality field parameter data were not collected due to meter malfunction. Substrate size parameters were calculated from pebble count data using the Reference Reach Spreadsheet (RRS), version 4.0. The RRS is a specialized Excel file developed by the Ohio Department of Natural Resources to manage channel survey data. The BEHI protocol was implemented for both banks; values reported in this document are the average of the right and left bank estimates.

All fecal coliform monitoring results and all field data collected by Equinox are listed in Appendix B. The field forms used by Equinox are shown in Appendix C. Duke Energy benthic monitoring data are presented in Section 3 of this report.

There is no stream gage in the Muddy Creek watershed. To provide information on water levels during the period of study, water level recorders (Global Water Model WL15 units, www.globalw.com) were installed at three sites in the watershed. These are submersible pressure transducers with a data logger, designed for the monitoring and recording of water levels. Units were programmed to record water levels at fifteen minute intervals and were

deployed from May 2006 to December 2007. The deployment period provided coverage of the 2006 and 2007 annual monitoring and most quarterly monitoring. The three sites included the lowest stations on South Muddy (Site 6) and North Muddy (Site 16) Creeks, as well as one on Bobs Creek (Site 25), a small tributary.

Data at the South Muddy Creek site were incomplete due to periodic meter malfunction. For approximately the last month of monitoring, recordings at the North Muddy Creek site were impacted by the presence of a log jam in the immediate vicinity of the instrument, which served to equalize water levels. Though beaver impoundments impacted water levels in portions of Bobs Creek, the stage recorder was located in an area unaffected by beaver activity. After downloading and evaluation for QA/QC, the data were analyzed to compile a data set of daily maximum stage levels for each site, which was used in subsequent analyses.

1.5 Supplemental Data

In developing this report, the data collected during the project was supplemented by data from a variety of other sources.

1. Past monitoring data collected by Duke and Equinox during prior assessment activities (2003 and earlier) are available at some monitoring sites. This includes benthic community data collected by Duke and pebble count data collected by Equinox. These data were collected by Duke and Equinox staff using methods identical or very similar to those to be used for the collection of new data during the current project.
2. Land cover change data are used to characterize watershed conditions. Analysis of land cover changes from 1998-2005, based on available digital orthophotography, was carried out by Equinox under contract to the NCWRC (Equinox, 2008).
3. Precipitation data from various sources and stream discharge data from nearby USGS gages are available.
4. At selected restoration sites, restoration design plans prepared by engineering and environmental firms provide stream morphology and benthic community data. Additionally, post-project site evaluations are being conducted at some sites, in particular natural channel design projects undertaken for compensatory mitigation purposes. These evaluations are currently in progress, but available information from these studies is included in the analyses reported here.

These sources are discussed in detail later in this document as the data are presented.

Section 2 Watershed Conditions

This section provides a summary characterization of the Muddy Creek watershed, including a discussion of land cover changes between 1998 and 2005. Relevant stream stage, discharge and meteorological data are also presented.

2.1 Watershed Characterization and Land Cover

Muddy Creek is a major tributary of the Catawba River located at the base of the Blue Ridge escarpment and draining about 111 square miles. Approximately one-half of the watershed lies in the Blue Ridge Foothills Level IV Ecoregion (Griffith et al, 2002), with the remainder in the Northern Inner Piedmont Ecoregion. While not mountainous, much of the watershed consists of rolling terrain with considerable relief. Elevations range from over 2,200 feet at the headwaters to about 1,000 feet at the confluence with the Catawba River.

Eighty-nine percent of the watershed is located in McDowell County, with the remainder located in Burke County. A small portion of the South Muddy Creek headwaters extends into Rutherford County. While McDowell and Burke Counties contain substantial National Forest lands, none are located in the Muddy Creek watershed.

Although the population of the Muddy Creek watershed is not known, McDowell County has an estimated 2006 population of 43,632 (N.C. State Data Center -<http://demog.state.nc.us/>). The City of Marion, the largest municipality in McDowell County (2006 population of 6,764), lies on the western edge of the Muddy Creek drainage. Most of the municipality lies within the watershed.

The most recent land cover data sets available for the watershed were developed from an interpretation of 1998 and 2005 digital orthophotos conducted by Equinox for the N.C. Wildlife Resources Commission (see Equinox, 2008, for a discussion of methods). These data (Table 2.1 and Figure 2.1) indicate that the Muddy Creek watershed was largely (75 percent) forested in 2005. Much of the forest land is actively managed; over 12,000 of the 53,000 forest acres (about 23 percent) were harvested in the 10 year period preceding 2005.

Agriculture has been an important historic activity in the watershed and remains so today, comprising 11 percent of the watershed in 2005, primarily in pasture. While this is only a small decline from the 12 percent level in 1998, it reflects a significant conversion of pasture and cropland to other uses (699 acres and 353 acres, respectively). The acreage classified as nurseries increased by 271 acres during this period.

Figure 2.1. 2005 Land Cover in the Muddy Creek Watershed

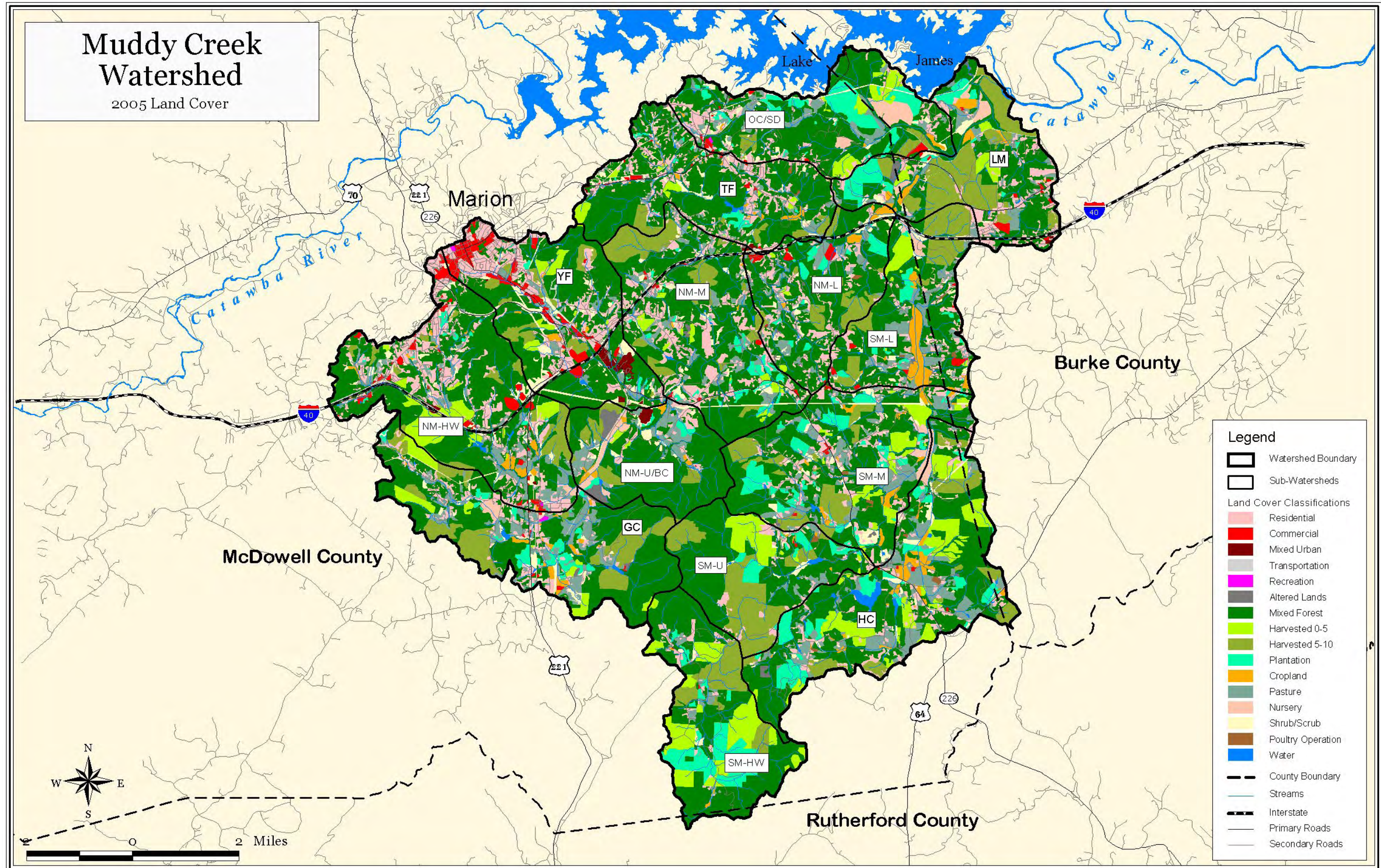


Table 2.1. Land Cover in the Muddy Creek Watershed, 1998 and 2005¹

Land Cover Classification	1998		2005		1998-2005
	Total Acres	Percent of Watershed Area	Total Acres	Percent of Watershed Area	Percent Change in Acreage
Forested	53,825	76.0%	53,096	75.0%	-1.4%
Mixed Forest	37,645	53.2%	34,360	48.5%	-8.7%
Harvested 5-10 yrs.	2,051	2.9%	7,994	11.3%	289.7%
Harvested 0-5 yrs.	5,158	7.3%	4,442	6.3%	-13.9%
Plantation	7,323	10.3%	3,962	5.6%	-45.9%
Shrub/Scrub	1,647	2.3%	2,338	3.3%	41.9%
Agricultural	8,609	12.2%	7,825	11.0%	-9.1%
Pasture	6,513	9.2%	5,814	8.2%	-10.7%
Cropland	1,560	2.2%	1,207	1.7%	-22.6%
Nursery	463	0.7%	734	1.0%	58.6%
Poultry Operation	73	0.1%	70	0.10%	-4.3%
Urban/Built Up	7,618	10.8%	9,296	13.2%	22.0%
Residential	6,084	8.6%	7,552	10.7%	24.1%
Commercial	899	1.3%	1,028	1.5%	14.4%
Transportation	465	0.7%	495	0.70%	6.4%
Mixed Urban	160	0.2%	200	0.28%	25.0%
Recreation	11	<0.1%	20	<0.1%	80.5%
Other	756	1.1%	592	0.8%	-21.7%
Altered Lands	513	0.7%	318	0.45%	-38.0%
Water	243	0.3%	274	0.39%	12.7%
Total	70,808	100.0%	70,808	100.0%	

(1) Data are from Equinox (2008). Cell entries may not add to totals because of rounding.

Of the major land cover categories, urban/built up land (developed areas, including highway corridors) experienced the greatest change during the seven year period, increasing from 10.8 percent of the watershed area in 1998 to 13.2 percent in 2005. A total of 1,678 acres was converted to urban use between 1998 and 2005, a 22 percent increase in the developed acreage in the watershed. While most (1,468 acres) of the new urban land was residential, increases in commercial use and other urban categories also occurred.

Land use classifications in the “Other” category include altered lands and water, which decreased by 164 acres. The decrease in areas classified as altered lands between 1998 and 2005 likely reflects conversion into urban/built up land. The total acreage classified as water increased by 30 acres, primarily reflecting the construction of new impoundments (both farm ponds and amenity impoundments in residential areas).

Land cover differs substantially by sub-watershed (Table 2.2). The upper portion of the South Muddy Creek drainage is >90 percent forest land. Sub-watersheds in this area also have the least amount of agricultural and urban/built up land. The lower South Muddy Creek, Hoppers Creek, Middle South Muddy and Upper North Muddy/Bobs Creek sub-watersheds have the highest percentage of agricultural land, exceeding 15 percent of sub-watershed area.

Table 2.2. Summary of Sub-Watershed Land Cover for Muddy Creek, 1998 and 2005

Sub-Watershed ID	Sub-Watershed Name	Total Area		Forested Acreage			Agricultural Acreage			Urban/Built Up Acreage			Other Acreage			
		Acres	Square Miles	1998	2005	% Change	1998	2005	% Change	1998	2005	% Change	1998	2005	% Change	
North Muddy Ck Drainage	NM-HW	North Muddy-Headwaters	6,844	10.7	4,539	4,538	<0.1%	792	693	-12.5%	1,421	1,584	11.5%	92	29	-68.6%
	GC	Goose Creek	5,982	9.3	4,620	4,601	-0.4%	971	865	-10.9%	342	465	36.1%	49	51	4.1%
	NM-U/BC	North Muddy-Upper/Bobs Ck	3,338	5.2	2,584	2,491	-3.6%	565	504	-10.8%	151	211	40.0%	39	133	241.4%
	YF	Youngs Fork	5,364	8.4	3,290	3,437	4.5%	288	261	-9.4%	1,578	1,650	4.5%	208	15	-92.6%
	NM-M	North Muddy-Middle	5,863	9.2	4,537	4,378	-3.5%	557	498	-10.6%	694	954	37.4%	75	33	-55.5%
	NM-L	North Muddy-Lower	3,749	5.9	2,832	2,750	-2.9%	514	425	-17.3%	393	555	41.3%	11	19	82.9%
	TF	Thompsons Fork	4,881	7.6	3,709	3,688	-0.6%	410	326	-20.3%	725	830	14.5%	38	37	-2.1%
South Muddy Ck Drainage	SM-HW	South Muddy-Headwaters	4,484	7.0	4,241	4,238	-0.1%	127	103	-19.0%	113	144	27.1%	3	0	-100.0%
	SM-U	South Muddy-Upper	3,795	5.9	3,534	3,463	-2.0%	143	130	-9.0%	85	186	117.5%	33	17	-48.8%
	SM-M	South Muddy-Middle	6,059	9.5	4,562	4,518	-1.0%	998	889	-10.9%	466	614	32.0%	34	38	12.1%
	HC	Hoppers Creek	7,067	11.0	5,443	5,278	-3.0%	1,275	1,181	-7.4%	231	461	99.4%	118	147	24.9%
	SM-L	South Muddy-Lower	4,002	6.3	2,831	2,764	-2.3%	798	768	-3.7%	369	457	23.8%	5	13	154.0%
Lower Muddy Ck	LM	Lower Muddy Creek	4,668	7.3	3,547	3,439	-3.0%	507	540	6.4%	572	636	11.1%	41	53	27.8%
	OC/SD	Old Catawba River/Shadrick Ck	4,711	7.4	3,555	3,513	-1.2%	666	643	-3.4%	479	548	14.4%	11	7	-37.7%

The Youngs Fork and North Muddy Creek Headwaters sub-watersheds, which contain portions of the City of Marion, have the greatest extent of built-up land in the watershed (30 percent and 23 percent, respectively). However, development in these areas does not appear to be increasing rapidly (5 percent to 12 percent increase in developed acreage between 1998 and 2005). The most substantial increase in developed land occurred in the Upper South Muddy and Hoppers Creek sub-watersheds, where the extent of built up land approximately doubled. Developed land increased by 40 percent in the Upper North Muddy and Lower North Muddy sub-watersheds.

While agricultural land was converted to other uses in all sub-watersheds, the greatest relative declines occurred in the Thompsons Fork sub-watershed where overall agricultural acreage declined by over 20 percent. Declines in agricultural acreage approached 20 percent in the Lower North Muddy and South Muddy Headwaters sub-watersheds.

Forest land increased only in the Youngs Fork drainage, apparently because of a reversion of some land to shrub/scrub cover, which is categorized as forest. The largest reductions in total forest acreage, on the order of three percent to four percent, occurred in the Upper and Middle North Muddy sub-watersheds, as well as in Hoppers Creek and in the Lower Muddy Creek drainage.

More detailed sub-watershed land cover data is located in Appendix D, Tables D.1 and D.2.

These data do not address changes occurring during the course of the monitoring project. The 2005 imagery predates the beginning of monitoring activities by several months. Building permit data for McDowell County are available for more recent years (Table 2.3). While these data pertain to the county as a whole and their applicability to the Muddy Creek watershed is not clear, they provide no reason to believe that the pace of growth in the Muddy Creek watershed documented by the land cover data is likely to have slowed in recent years.

Table 2.3. Single Family Residential Building Permits Issued in McDowell County, 1998-2007

Year	Single Family Permits Issued
2007	256
2006	216
2005	211
2004	231
2003	160
2002	169
2001	123
2000	122
1999	133
1998	126

Notes: Includes permits issued by McDowell County and municipalities. Very few permits for multi-family housing were issued during these years.

Source: U.S. Census Bureau (downloaded from <http://censtats.census.gov/bldg/bldgprmt.shtml> on May 2, 2008).

2.2 Meteorological Conditions

Long term weather data are available for a National Weather Service (NWS) Cooperative Station located in Marion (Station No. 315340, CRONOS Data Base of the N.C. State Climate Office, <http://www.nc-climate.ncsu.edu/cronos>), at the western edge of the Muddy Creek watershed. Data are also collected at the Marion wastewater treatment plant, but long term statistics for this site are not readily available. Precipitation at the NWS station averages 54 inches per year, with monthly averages ranging from 3.9 to 5.6 inches (1971-2000 30 year average, calculated by N.C. Climate Office). Precipitation was near normal during 2005 (95 percent of long term average levels), but declined progressively during the remainder of the monitoring period— to 88 percent of normal in 2006 and 73 percent of normal in 2007. See Figure D1 in Appendix D for monthly precipitation data.

Progressively worsening drought conditions were common throughout much of North Carolina during 2006 and 2007, including McDowell County. The N.C. Drought Monitoring Advisory Council (www.ncdrought.org) classified drought conditions in the County as severe or worse during most of 2007 (Figure 2.2).

2.3 Stream Discharge and Stage During Monitoring Period

There is no stream gage within the Muddy Creek watershed. The nearest gaging station is on the Catawba River near Pleasant Gardens (USGS Gage No. 02137727) located upstream of Lake James. This gage is in close proximity to Muddy Creek, about two miles outside of the northwest corner of the watershed, drains an area of similar size (126 square miles) and the rainfall regime is probably more similar to Muddy Creek than other gages in the vicinity. Discharges at this gage progressively declined over the monitoring period (Figure 2.3). Discharges were above normal for nine months of 2005, including all of the months during which monitoring was conducted. Flows were below normal for 9 months in 2006 and 11 months of 2007 and were approximately 50 percent of normal or less during the last seven months of 2007. During the periods each year when most annual monitoring was conducted, mean monthly flows compared to long term averages show significant declines each year (Table 2.4). Other gages in the surrounding area (e.g. the USGS gage on Henry Fork, predominately draining Burke County) show a similar pattern to the Catawba River gage.

Table 2.4. Discharge During Annual Monitoring Compared to Long Term Average (1980-2007)

Year	Period of Annual Monitoring in Muddy Creek	Catawba River Discharge as % of Long Term Monthly Average ¹
2005	June-October	193%
2006	July-October	96%
2007	July-November	33%

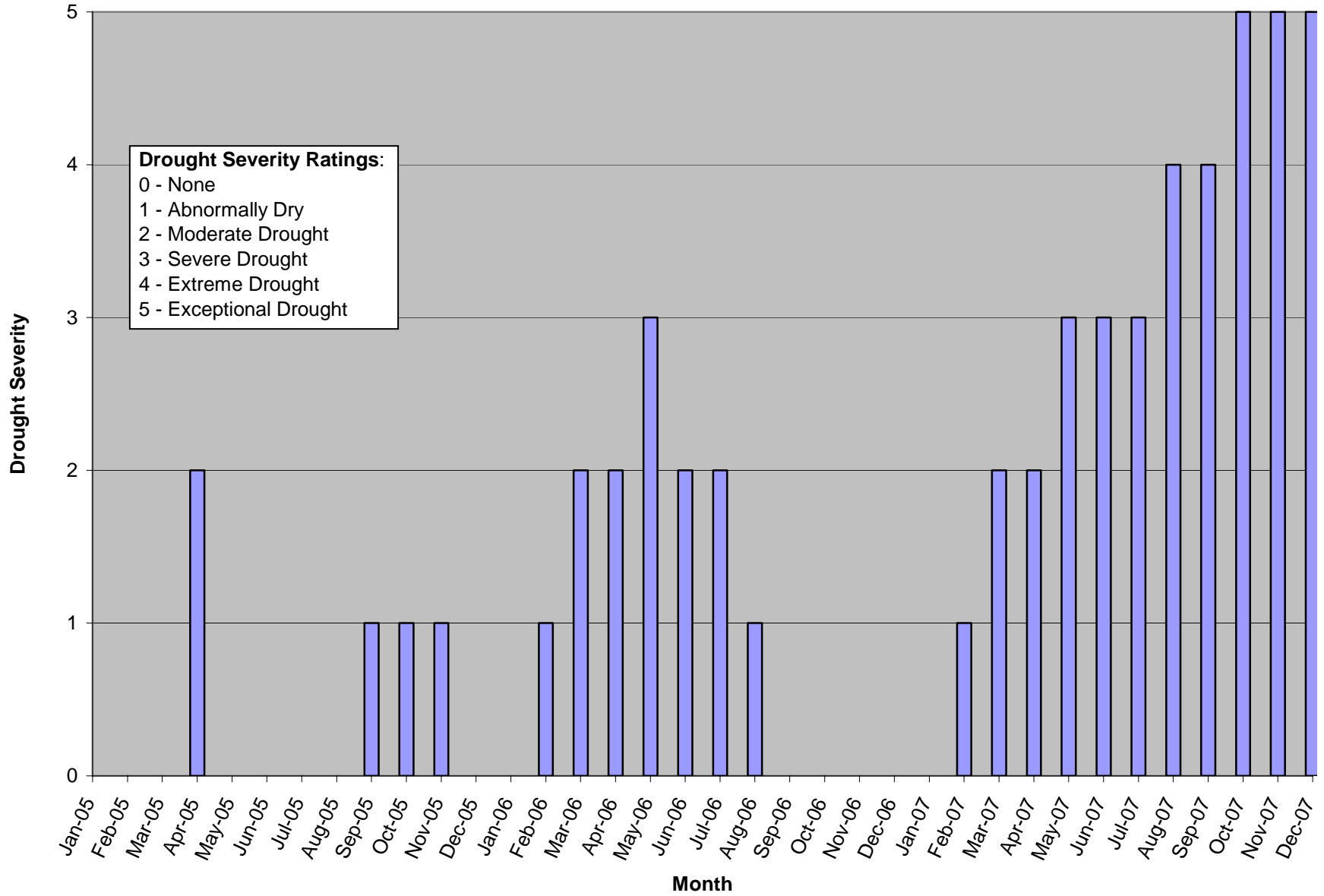
(1) Catawba River at Pleasant Gardens, USGS Gage No. 02137727.

Progressively lower discharges and rainfall during the monitoring period would, other considerations being equal, result in lower rates of upland erosion and lower inputs of upland sediment and other pollutants to streams. Lower discharges would likely also result in lower

rates of stream bank erosion and would reduce transport rates for channel sediment, especially for bedload.

The three digital stage recorders deployed in the Muddy Creek watershed from May 2006 to December 2007 provide confirmation of the applicability of the Catawba River discharge data. Stage data for North Muddy Creek (Site 16) confirm the paucity of storms during 2007, especially in the final eight months of the year (Figure 2.4). Wastewater discharges from the Marion WWTP provided some baseflow to North Muddy Creek even during the worst of the drought. Storm peaks in North Muddy Creek are generally quite consistent with discharge peaks at the Catawba River gage. The stage data for South Muddy Creek (Site 6) and Bobs Creek (Site 25) show the same overall patterns, with the impact of large storm events evident on the same date as North Muddy Creek (see Appendix D, Figures D.2 and D.3). Low water levels during the summer of 2007 were particularly evident in Bobs Creek, which drains only two square miles.

Figure 2.2. Drought Severity in McDowell County, 2005-2007



(Source: N.C. Drought Monitoring Advisory Council, www.ncdrought.org)

Figure 2.3. Catawba River near Pleasant Gardens (USGS Gage No. 02137727): 2005-2007 Monthly Discharge and Long Term Monthly Averages

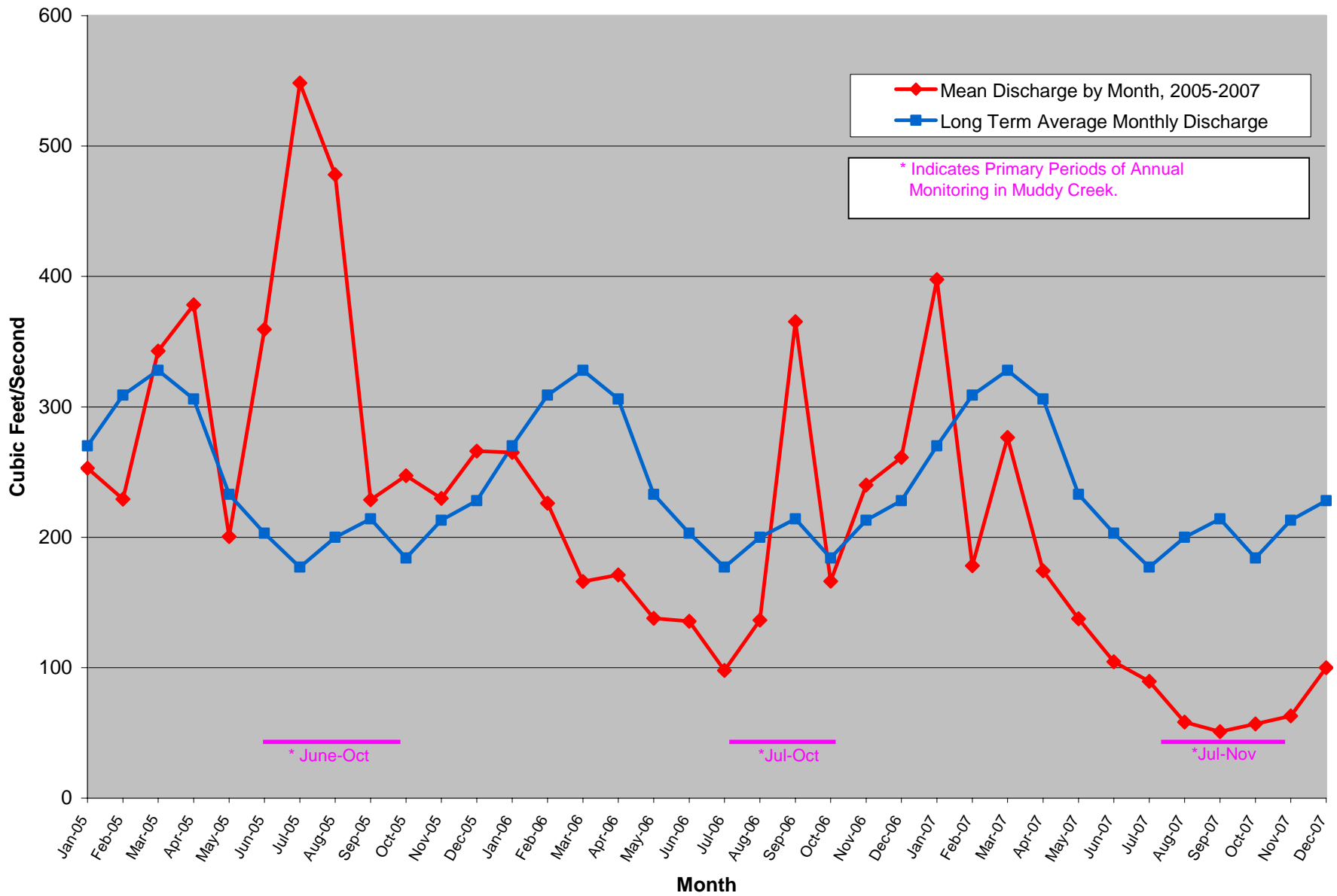
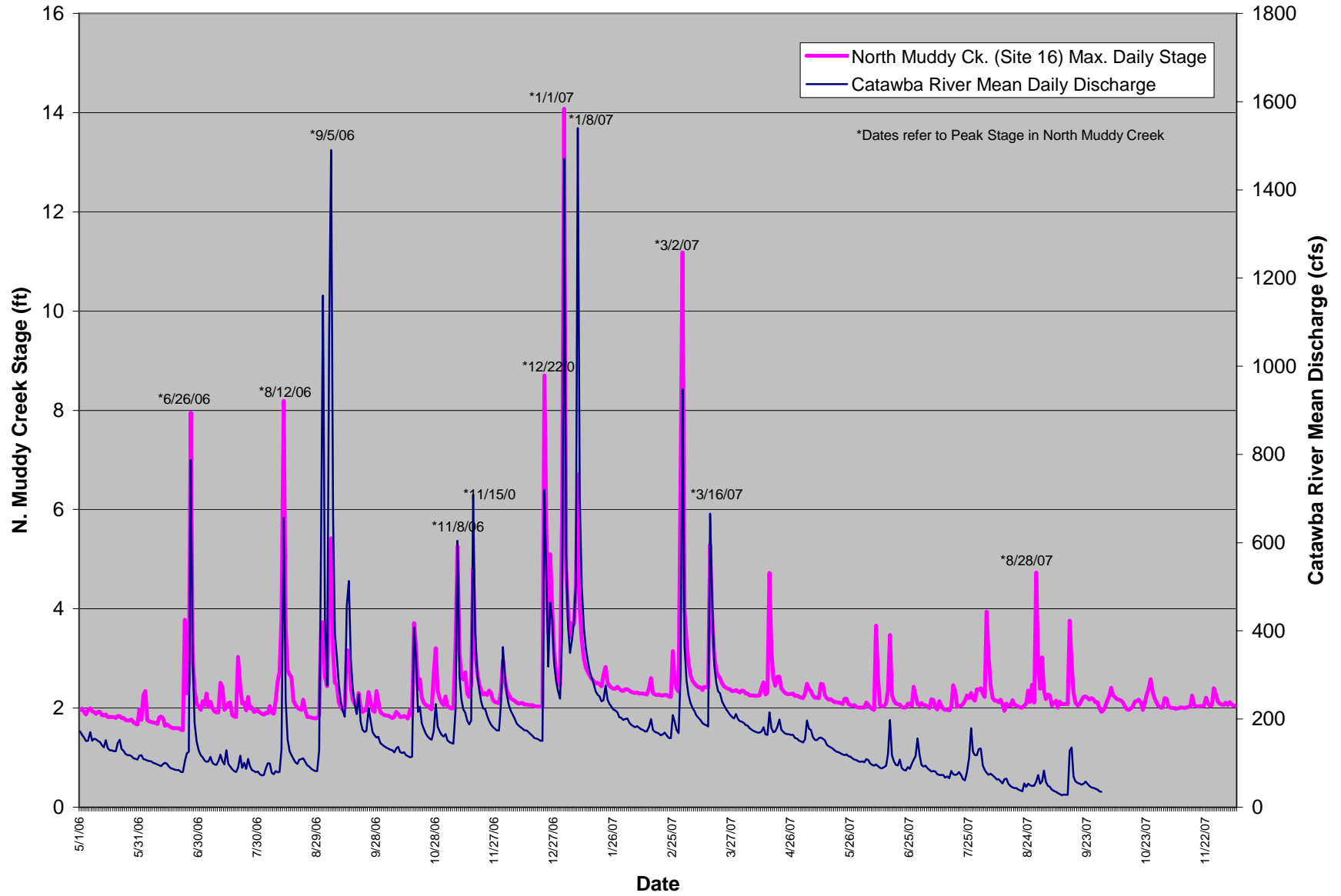


Figure 2.4. Stage in North Muddy Creek (Site 16) vs. Discharge in the Catawba River (Pleasant Gardens), May 2006-December 2007



Section 3 Overview of Stream Conditions and Water Quality

This section presents an overview of water quality and stream conditions in the Muddy Creek watershed based upon the 2005-2007 data collected during this project. All fecal coliform data collected (nine sites) and all benthic community data collected by Duke Energy (four sites) are discussed, followed by a summary of selected physical indicators. This review is general in nature and does not address restoration impacts, which are discussed in Section 5.

3.1 Benthic Community Condition

Benthic monitoring was conducted by Duke Energy using NCDWQ's standard qualitative method (NCDWQ, 2003). Data from the sites at the downstream end of North Muddy Creek (Site 16) and South Muddy Creek (Site 6) provide a synoptic picture of overall water quality in these drainages. Both sites received a rating of Good-Fair during all three years of monitoring, reflecting notable degradation in the status of biological communities, although these waters would not be considered impaired by NCDWQ (Table 3.1). Biotic Index (BI) values were elevated, indicating benthic communities where pollution tolerant organisms were prominent. This represents an improvement from conditions documented by Duke Energy monitoring in 2001-2004, when both of these stations were rated either Fair or Poor, indicative of impaired conditions (Appendix D, Table D.3).

The other two sites monitored by Duke are too small to receive a formal rating using NCDWQ criteria. In this situation, NCDWQ considers a stream meeting the standard criteria for a Good-Fair rating or higher to be Not Impaired, while a stream not meeting these criteria would be considered Not Rated. Based on this approach, the benthic community in Bobs Creek would be considered Not Impaired, although BI levels are elevated. The situation is less clear in South Fork Hoppers Creek, which would be considered Not Rated by NCDWQ. The benthic community in South Fork Hoppers Creek declined sharply in 2006, likely due to the impacts of in-stream construction activity from a restoration project. This site will be discussed further in Section 5.

NCDWQ monitored benthic macroinvertebrate and fish communities in North and South Muddy Creeks in 2007 as part of the monitoring it conducts in the Catawba River basin every five years. The sites assessed were some distance upstream from the Duke monitoring sites. Macroinvertebrate communities received a bioclassification of Good-Fair in North Muddy Creek and Good in South Muddy Creek (Appendix D, Table D.4), while the fish communities in these streams received ratings of Excellent and Good, respectively (Appendix D, Table D.5).

3.2 Fecal Coliform Bacteria

High levels of fecal coliform bacteria were found throughout the watershed during each year monitored (Figure 3.1). Among the eight sites monitored for all three years, five exceeded the state standard (geometric mean of 200 colonies/100 ml based on at least five samples in 30 days) in 2005. All sites exceeded the state standard in 2006 and 2007, often by a wide margin. Progressive declines in annual discharge and rainfall during the monitoring period may have contributed to this pattern, although changes in pollution inputs or other factors may also be at

play. Data for 2007 were analyzed using a different laboratory technique than in the prior two years (see Section 1). While fecal coliform levels declined at the majority of sites in 2007 compared to 2006, all sites continue to be well above the standard.

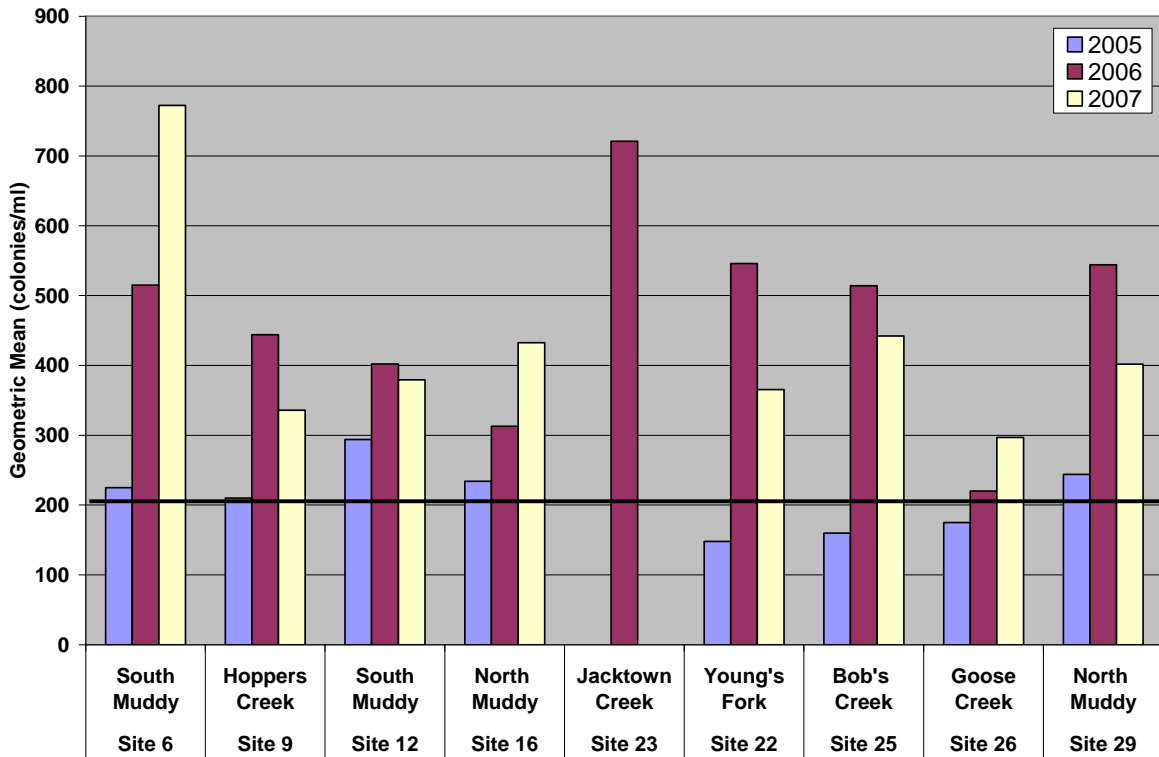
Table 3.1. Benthic Community Data 2005 – 2007 for Sites Monitored by Duke Energy¹

Site & Indicator	Monitoring Year		
	2005	2006	2007
Site 6 South Muddy Ck			
Total EPT Taxa	28	23	24
Biotic Index	4.75	4.66	5.15
Bioclassification	Good-Fair	Good-Fair	Good-Fair
Site 16 North Muddy Ck			
Total EPT Taxa	25	22	28
Biotic Index	5.09	5.76	5.74
Bioclassification	Good-Fair	Good-Fair	Good-Fair
Site 10 South Fork Hoppers Ck²			
Total EPT Taxa	26	13	16
Biotic Index	4.65	6.60	6.53
Bioclassification	Good ²	Fair ²	Fair ²
Site 25 Bobs Ck²			
Total EPT Taxa	23	31	24
Biotic Index	4.69	5.20	5.34
Bioclassification	Good-Fair ²	Good-Fair ²	Good-Fair ²

(1) Project monitoring dates: July 26, 2005; July 19, 2006; July 23, 2007.

(2) The Division of Water Quality would likely not assign a bioclassification to Sites 10 and 25 because these stations fall below the 3 square mile drainage area threshold generally used to apply the rating system. For sites <3 mi² DWQ would normally consider a condition that appears to reflect a Good or Good-Fair to indicate that the stream is not impaired (NI), but the agency would not apply a formal bioclassification. Samples with a condition that appears to reflect Fair or Poor conditions would be classed as not rated (NR). Bioclassifications of Poor and Fair indicate impairment.

Figure 3.1. Fecal Coliform Results for the Muddy Creek Watershed, 2005-2007



3.3 Physical Indicators

Data on selected physical indicators were summarized for the thirteen monitoring sites intended to represent individual sub-watersheds, as well as for three sites on the Catawba River below its confluence with Muddy Creek (Table 3.2). This excludes most of study sites where stream improvements are completed or underway, which are located primarily on smaller streams; restoration projects have been completed at only two of these sites (Sites 9 and 27) and are currently underway at another (Site 18). The indicators discussed include aquatic habitat, riffle embeddedness, bank erosion and specific conductance. The figures present either the mean or median of the three annual observations for each indicator, as noted on each chart.

Table 3.2. Monitoring Sites for Which Physical Indicators are Summarized

Site ID # ¹	Stream Name	Sub-Watershed	Sub-Watershed ID
29	North Muddy Creek	North Muddy-Headwaters	NM-HW
27	Goose Creek	Goose Creek	GC
24	North Muddy Creek	North Muddy-Upper/Bobs Creek	NM-U/BC
22	Youngs Fork	Youngs Fork	YF
19	North Muddy Creek	North Muddy-Middle	NM-M
18	Thompsons Fork	Thompsons Fork	TF
16	North Muddy Creek	North Muddy-Lower	NM-L
13	South Muddy Creek	South Muddy-Upper	SM-U
9	Hoppers Creek	Hoppers Creek	HC
8	South Muddy Creek	South Muddy-Middle	SM-M
6	South Muddy Creek	South Muddy-Lower	SM-L
4	Old Catawba River	Old Catawba River/Shadrick Creek	OC/SD
5	Muddy Creek	Lower Muddy Creek	LM
1	Catawba River	Catawba River	Not Applicable
2	Catawba River	Catawba River	Not Applicable
3	Catawba River	Catawba River	Not Applicable

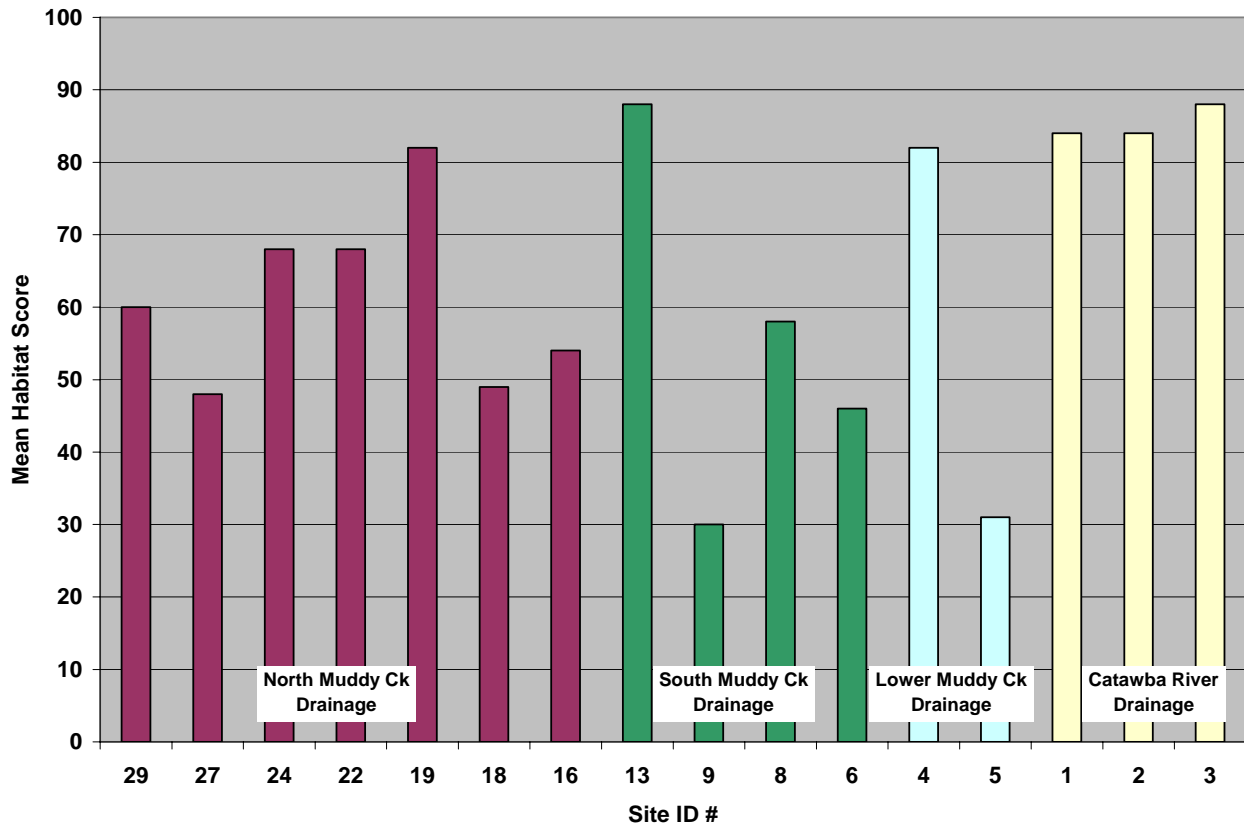
(1) Site IDs refer to Figure 1.2.

3.3.1 Aquatic Habitat

Aquatic habitat quality was assessed using the NCDWQ habitat protocol (Section 1), which rates stream reaches on a scale from zero (lowest) to one hundred (highest), based upon scores of eight individual habitat metrics. The most recent NCDWQ Basinwide Assessment Report for the Catawba River Basin (NCDWQ, 2008) uses a score of 65 out of 100 as the cut off between high-moderate and low-poor aquatic habitat quality. Furthermore, the report reveals that within the upper Catawba River basin the highest quality sites have scores in the upper 80's and low 90's (NCDWQ, 2008). Those ratings are assumed to represent reference conditions for the region.

Aquatic habitat conditions in the Muddy Creek watershed (Figure 3.2) are highly variable, ranging from high quality habitat at a few North Muddy Creek and South Muddy Creek sites (e.g. Sites 19 and 13) to very poor conditions at other locations (e.g. Hoppers Creek, Site 9, and Muddy Creek mainstem, Site 5). Overall, habitat in the South Muddy Creek drainage is more degraded (75 percent of sites with a mean score of <65) than in the North Muddy Creek drainage (57 percent of sites with a mean score of <65). Habitat in the Catawba River was consistently good (scores of 80 to 90).

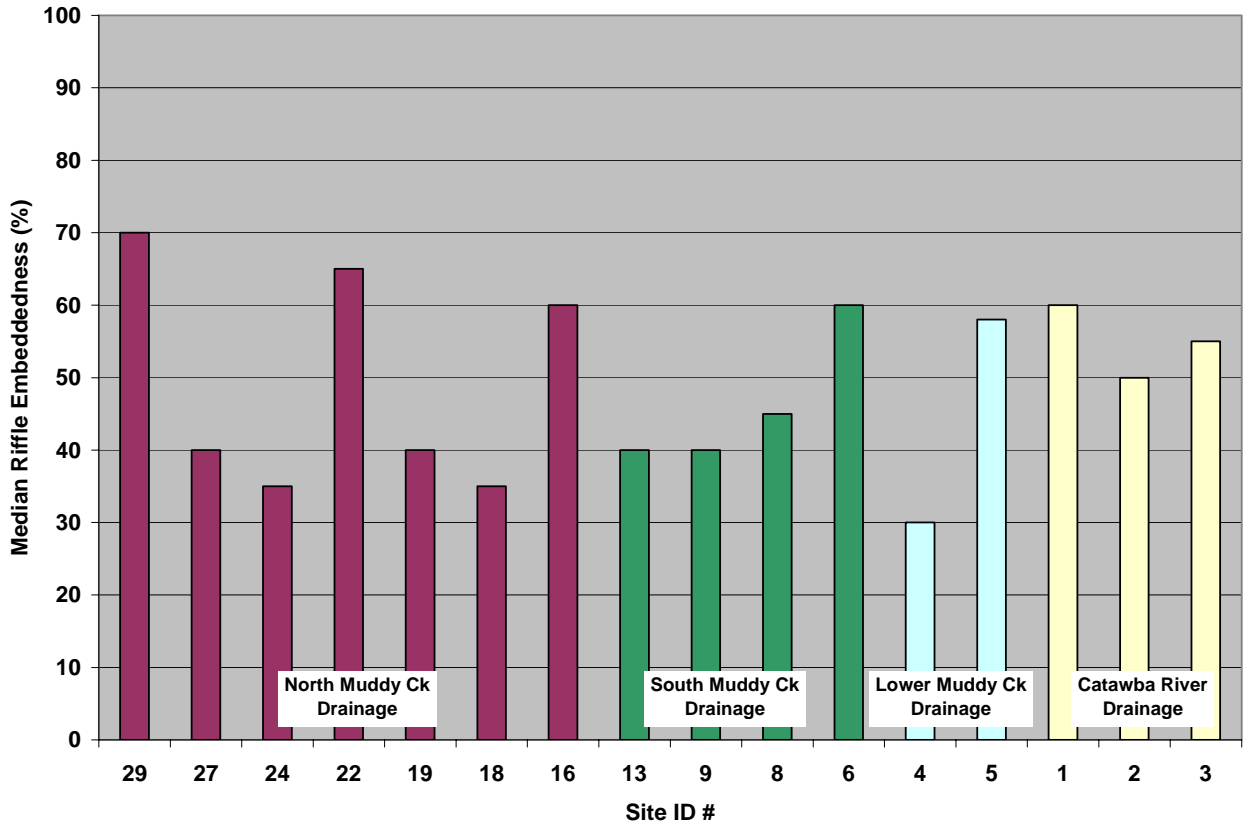
Figure 3.2. Aquatic Habitat Scores (Three-Year Means) in the Muddy Creek Watershed



3.3.2 Riffle Embeddedness

Riffle embeddedness data indicate excessive sedimentation in the Muddy Creek watershed as well as in the mainstem Catawba River below its confluence with Muddy Creek (Figure 3.3). At least moderate embeddedness (≥ 40 percent) is evident at the vast majority of sites, while high levels (≥ 60 percent) were found at several North Muddy Creek sites (Sites 16 and 29), in Youngs Fork (Site 22), at the downstream site on South Muddy Creek (Site 6), and at one of the Catawba River locations (Site 1). The three year median scores for 71 percent of the sites in the North Muddy Creek drainage and all of the South Muddy Creek sites were ≥ 40 percent, which is indicative of substantial riffle habitat loss. While habitat scores between sites were relatively stable between years, embeddedness is more variable due to changes in sediment supply and fluctuation in bed load transport associated with storm events (see Appendix F for additional discussion of variability).

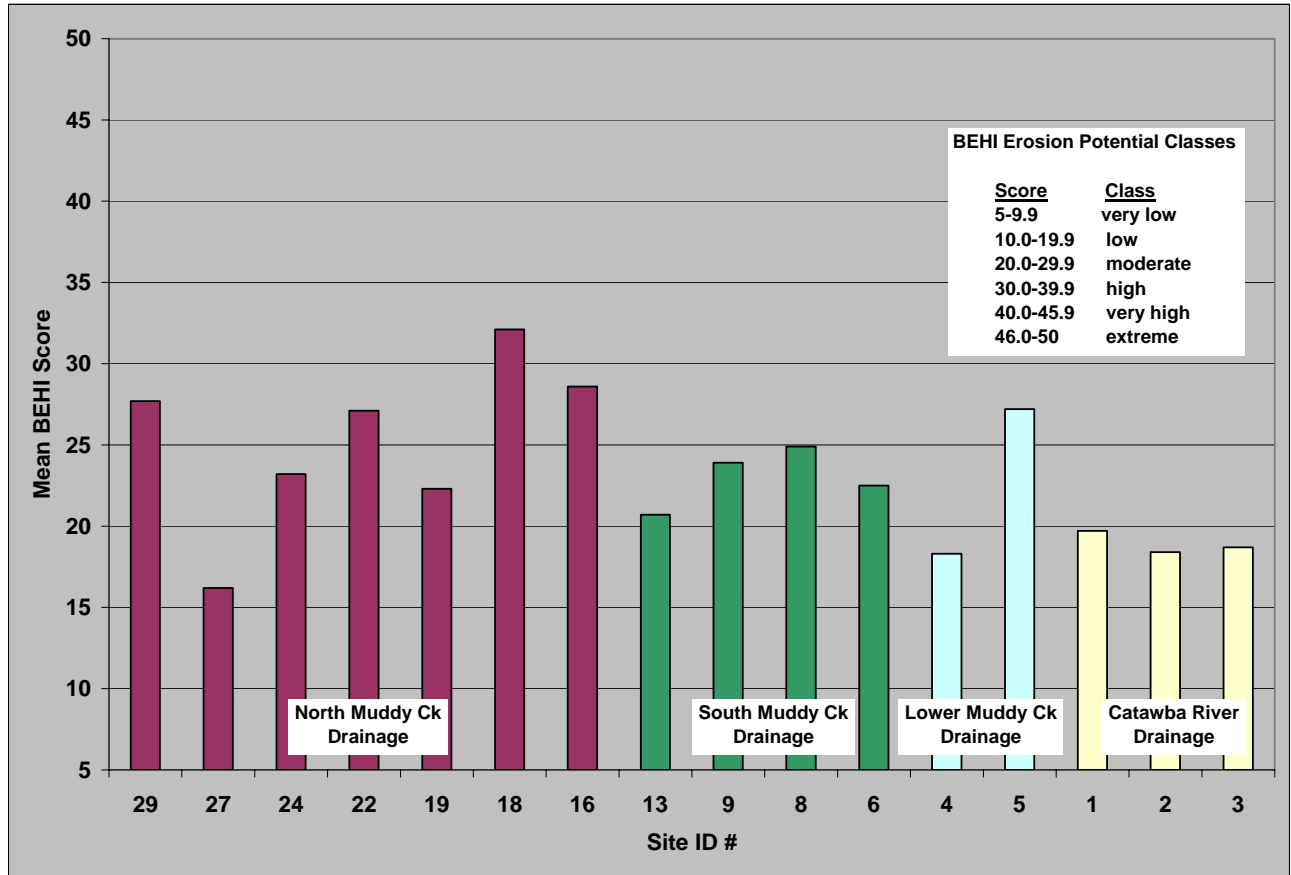
Figure 3.3. Riffle Embeddedness (Three-Year Medians) in the Muddy Creek Watershed



3.3.3 Bank Erosion

BEHI scores (average of typical right and left bank conditions at each site) indicate that bank erosion potential is in the moderate range (scores of 20-30, per Rosgen, 1996) for most sub-watershed sites in the Muddy Creek watershed (Figure 3.4). Erosion potential in the high range (score of 30-40) was found only in Thompsons Fork (Site 18); a natural channel design restoration project has since been initiated at this site. Low erosion potential (score <20) is evident only in Goose Creek (Site 27), Old Catawba River (Site 4) and on the Catawba River mainstem (Sites 1-3).

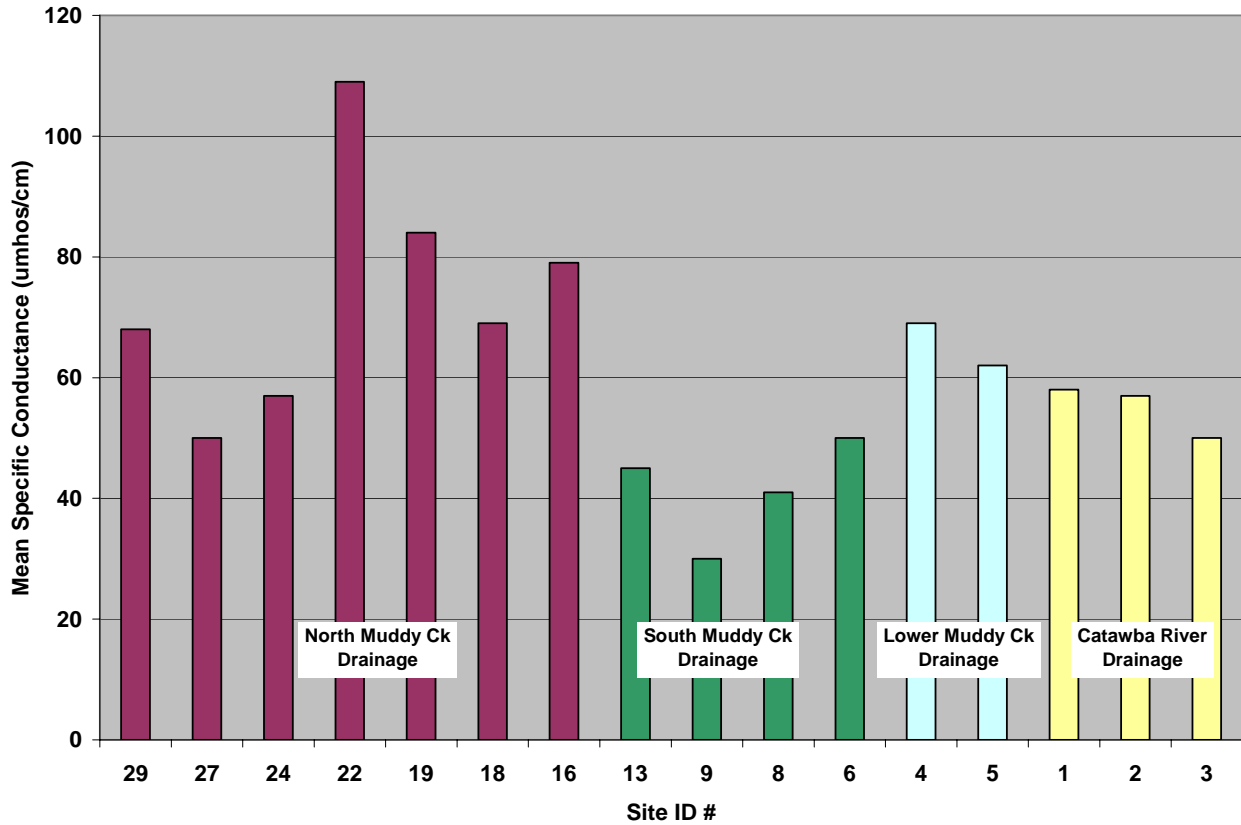
Figure 3.4. BEHI Scores (Three-Year Means) in the Muddy Creek Watershed



3.3.4 Specific Conductance

Typical conductivity values for mainly forested sites sampled by the Volunteer Water Information Network (University of N.C., Asheville, Environmental Quality Institute) in the mountain region are $\leq 30 \mu\text{mhos/cm}$ (Maas et al, 2004). Specific conductance exceeds this level at virtually all sites in the Muddy Creek watershed (Figure 3.5). Mean conductivity is $>40 \mu\text{mhos/cm}$ at most sites in the South Muddy Creek drainage. Conductivity exceeds $60 \mu\text{mhos/cm}$ at most sites in the North Muddy Creek drainage, likely reflecting the diverse sources of pollution associated with the more widespread development in this portion of the watershed. Only Hoppers Creek (Site 9) had a mean conductivity of $\leq 30 \mu\text{mhos/cm}$.

Figure 3.5. Specific Conductance Data (Three-Year Means) for the Muddy Creek Watershed



3.4 Summary

The following broad conclusions regarding stream condition can be drawn from the data collection efforts during 2005-2007:

- Benthic community data collected by Duke Energy on North and South Muddy Creeks indicate a system under stress, with pollution tolerant organisms prominent. NCDWQ biological community data (benthos and fish), collected at different sites on these streams, indicate somewhat better conditions in most cases.
- The Duke and NCDWQ biological community data generally indicate that both North and South Muddy Creeks have improved between 2002 and 2007. The reasons for this improvement are not clear, although NCDWQ believes that lower nonpoint source inputs due to the drought may be responsible for improved conditions at some locations (NCDWQ, 2008).
- Contamination from fecal coliform bacteria is a major concern. Violations of the State water quality standard for fecal coliform are widespread, occurring consistently at most sites during the three-year period.
- Impacts of sedimentation on riffle habitat occur widely throughout the watershed. Riffle embeddedness is moderate or worse at most sites, indicating substantial loss of this important habitat type.

- Substantial aquatic habitat degradation is evident at most sites, especially in the South Muddy Creek drainage.
- Moderate bank erosion potential is evident at most sub-watershed sites in the Muddy Creek watershed.
- Conductivity levels at most sites, especially in the North Muddy Creek drainage, are well above normal background levels (Maas et al, 2004) and reflect pollutant inputs.

Section 4 Status of Restoration Projects

Numerous stream improvement projects have been implemented by the MCRP over the past decade. While some of these were monitored as part of the current project, others were not. In order to provide a context for the analysis of restoration impacts to follow, this section summarizes the current status of restoration projects completed to date, providing information on projects undertaken at monitoring sites, as well as a broader view of restoration at the sub-watershed scale.

Projects undertaken in the Muddy Creek watershed, while generally identified and facilitated by the MCRP, have been funded and overseen by a number of different agencies. Funding agencies have specific objectives for their projects. These generally overlap with but differ from the primary objectives of the MCRP, which are focused first and foremost on reducing sediment impacts. Some of the projects, notably those funded by NCEEP, were undertaken for compensatory mitigation purposes.

4.1 Types of Projects Implemented

Three types of stream improvement projects have been implemented by the MCRP:

Natural channel design stream restoration (NCD). These projects involve the reestablishment of stable channel morphology to stream reaches that are unstable due to past channelization or other factors. A new stable channel may be constructed with appropriate morphology and habitat features. Alternatively, the existing channel can be modified to stabilize banks and beds and to reestablish meanders, riffles, pools and other features. In-stream and bank structures may be installed to promote stability and enhance aquatic habitat. Banks and riparian areas are revegetated and livestock exclusion practices may be installed. A minimum permanent conservation easement width of 30 feet on each bank is currently required by most agencies, though actual width can vary and easements were not required on some early projects in the watershed. Channel design methodology is usually based on the general approach advocated by Rosgen (1998 and 2006). Projects of this type may be funded by the N.C. Ecosystem Enhancement Program, the N.C. Clean Water Management Trust Fund or other sources.

Livestock exclusion. These projects involve the fencing of livestock (usually cattle or horses) out of stream channels, in conjunction with providing alternative watering sources. Other farm management practices (BMPs) may also be implemented to reduce potential pollutant inputs (e.g. feeding areas or livestock trails), and engineered stream crossings are provided in some cases. The location of fencing relative to the stream varies, although 10-15 feet from the top of the stream bank is typical. The active reestablishment of riparian vegetation is generally not carried out as part of livestock exclusion, although a revegetation project may at times be implemented at the same site. These projects do not involve the repair of any ongoing stream bank erosion. Projects are typically funded under the USDA Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) or the N.C. Agricultural Cost Share Program (NCACS). These programs require the landowner to make a matching contribution of either money or labor or both.

Riparian area revegetation. These projects, funded through a variety of sources, involve the replanting of riparian areas with native woody vegetation. The size of the revegetated zone varies, but 20 feet from the top of the existing bank is a typical width. Easements have not been required on revegetation projects in the Muddy Creek watershed. Any eroding stream banks present are not generally repaired. Revegetation projects are not implemented where livestock continue to have access to the area.

4.2 Expected Project Impacts

Prior to evaluating the effects of any restoration effort, it is important to understand the nature and timing of the improvements that one might anticipate from these activities. The summary below provides a generalized picture of these effects. Expected effects at any particular site will depend upon the nature and degree of existing degradation, the details of project design and implementation, and a variety of other factors.

Expected effects at natural channel design projects:

- In general, these projects provide an immediate reduction in some aspects of stream degradation (e.g. reduced erosion). For other conditions, a project sets in motion a process of self-renewal that will take some time to complete.
- An immediate positive impact on bank stability (e.g. BEHI ratings) would be expected, as steep and eroding banks are repaired or reconstructed during the project. Bank stability would be expected to continue to improve for some time, as woody vegetation becomes established.
- An immediate positive impact on some aquatic habitat components is likely, since these are reworked or established during construction (e.g. channel sinuosity, thalweg depth and extent of pools). Other habitat features (especially those dependent upon vegetation) may improve only gradually. The full reestablishment of riparian vegetation, as well as the resupply of woody material to the channel, may take years or decades.
- Some components of stream substrate may improve immediately if riffles are constructed in their entirety. At some sites, however, stream gradient is modified to establish riffles, but coarse riffle substrate material is not imported. This approach relies on the stream to flush out fine materials and deposit appropriate coarser bed material over time.
- Although improved aquatic habitat can allow for substantial improvements in the benthic macroinvertebrate community over the long run, the construction process is likely to be very disruptive to the existing benthic population. The time frame for post-project benthic community recolonization depends upon a variety of factors, including how long it takes the habitat within the restored stream to stabilize and the condition of the watershed upstream of the site.

Expected effects at livestock exclusion projects:

- In general, these projects involve fencing out livestock and may eliminate or drastically reduce direct inputs of pollutants such as nutrients, bacteria and sediment. However, exclusion projects do not provide an immediate fix for most forms of existing degradation. For the most part these projects serve to remove an ongoing stressor (livestock impacts on vegetation and channel morphology) so that the stream can heal itself over time.

- Revegetation occurs naturally once livestock are removed, but it may take a number of years for woody growth to become reestablished to the point where it substantially reduces bank instability or contributes to aquatic habitat improvement.
- Similarly, bank condition will gradually improve over time, but large improvements are not likely in the short term. Unstable banks may continue to be unstable for some time, especially if the stream is incised, and some sediment will continue to be generated until a stable condition is attained.
- While a project may eliminate disturbance of stream substrate by livestock and the resulting resuspension of materials, it will do nothing to remedy existing deficiencies such as highly embedded riffles or sedimented pools. Assuming that upstream sources of sediment are not a major consideration, the substrate may be expected to improve gradually as inputs from bank erosion within the reach decline and existing sediment is flushed down the channel.
- Aquatic habitat will improve over time as the processes described above occur.
- The benthic macroinvertebrate community will improve gradually as habitat improves, though it may benefit in the short term from the removal of livestock trampling. Unlike natural channel design projects, livestock exclusion efforts should have no negative short-term impact on benthos.

Expected effects at revegetation projects:

- Many of the comments made for livestock improvement projects also apply here. One major difference is that vegetation reestablishment may occur more quickly than for livestock exclusion since planting of vegetation is the primary project activity. Revegetation projects would generally not be undertaken in reaches where ongoing livestock access is a concern.

The type and extent of improvement one should anticipate from a stream project is clearly dependent on the time elapsed between project completion and the monitoring conducted (in the case of vegetation, the number of growing seasons). For NCD projects, one would generally anticipate a reduction in bank erosion potential and degradation of the aquatic habitat in the first year. Other indicators (e.g. riffle substrate) may or may not improve in the short term, and lack of improvement in the first year would not be surprising. For livestock exclusion and revegetation projects, it is possible that no indicators will improve measurably by the initial monitoring event, especially if a growing season has not yet elapsed.

These conclusions assume that upstream disturbances do not significantly affect the restored stream reach. For example, substrate improvements may not occur over any time frame if much of the sediment supply to the reach comes from upstream of the project.

4.3 Status of Restoration Efforts at Project Monitoring Sites

At the beginning of this project, 11 sites were selected for monitoring where restoration was anticipated to be completed prior to the end of the monitoring period (refer to Table 1.1). However, implementation of stream improvement projects at a number of locations progressed more slowly than originally foreseen, due to rescheduling of work by government agencies, delays in project design and other factors. To date restoration activities are complete at seven of

these sites, while design or construction are still underway at the remaining four. The current status of activities at these sites is summarized in Table 4.1.

Additionally, four sites at which no stream improvement projects were anticipated were initially selected as comparison sites (Table 1.1). The situation has changed at two of these sites (Table 4.1) and restoration projects are now planned at these locations, although no construction activities have been initiated.

The analysis of site-specific restoration impacts must necessarily be limited to the seven locations at which restoration is complete. The remaining eight sites could be used for comparison purposes (see discussion in Section 5).

Table 4.1. Current Project Status at Monitored Restoration and Comparison Stations, Muddy Creek Watershed

Monitoring Site				Restoration Project Information			Years of Monitoring Data ³	
Station ID #	Stream Name	Road Name	Drainage Area (mi ²)	Current Restoration Status ²	Project Type ⁴	Project Length (linear feet)	Pre	Post
Restoration Completed Prior to Initiation of Monitoring Project								
25	Bobs Creek	Marlowe Road	2.1	Completed Spring 2002	NCD	1,900	0	3
27	Goose Creek	Huntsville Road	9.1	Completed Fall 2002	REV, LE	3,200	0	3
09	Hoppers Creek	Dysartsville Road	9.3	Completed Spring 2004 (repairs in 2006)	NCD	1,000	0	3
Restoration Completed Between Year 1 and Year 2 Monitoring								
07	Patten Branch	Muddy Creek Road	2.1	Completed Spring 2006	NCD	14,500	1	2
10	S. Fork Hoppers Ck.	SR 1776	1.3	Completed Spring 2006	NCD, LE	7,200	1	2
Restoration Completed Between Year 2 and Year 3 Monitoring								
28	UT to Goose Ck.	SR 1785	0.4	Completed Fall 2007	LE	7,600	2	1
21	Bledsoe Branch	Deacon Road	0.7	Completed Fall 2007	NCD, LE	5,000	2	1
Restoration Currently Underway or Planned								
20	Big Camp Creek	Burma Road	2.6	Under Construction (Began Summer 2005)	LE	1,500	3	0
18	Thompsons Fork	South Creek Road	7.6	Under Construction (Began Fall 2007)	NCD, LE	5,000	3	0
12	South Muddy Ck.	Sain Road	18.7	Design	NCD	2,800	3	0
17	UT to N. Muddy Ck.	Gilbert Byrd Road	0.1	Design	LE	1000	3	0
23 ¹	Jacktown Creek	Hwy 226	1.3	Design	NCD	800	3	0
11 ¹	S. Fork Hoppers Ck.	Landis Lane	0.5	Design	NCD, LE	3,800	3	0
No Restoration Currently Planned								
14 ¹	High Shoals Creek	Vein Mountain Rd	2.5	-	-	-	3	0
15 ¹	UT to S. Muddy Ck.	Brckett Town Road	0.5	-	-	-	3	0

(1) Initially classified as comparison site. All other stations initially classified as restoration sites.

(2) Status as of October 2007. Project at Site 20 has since been completed, but livestock at this site still had stream access at the time of Year 3 monitoring.

(3) Includes data from current monitoring project only. Additional pre data are available at some sites from other sources.

(4) Key to Project Types: NCD = natural channel design stream restoration (includes revegetation).

REV = riparian area revegetation only.

LE = livestock exclusion (no revegetation unless otherwise specified).

4.4 Cumulative Restoration Activity at the Sub-Watershed Level

In addition to the restoration project sites monitored during this project, ten other stream improvement projects, totaling about 13,000 linear feet, had been completed in the Muddy Creek watershed by the time the final round of monitoring was conducted in 2007 (Table 4.2). One additional project, also listed in Table 4.2, was completed in early 2008. Numerous others are under some stage of development (e.g. negotiations with landowners, design).

Considering all projects, monitored and unmonitored, stream improvement activities have been completed on approximately 50,200 linear feet (>9 miles) of stream in the Muddy Creek watershed (Figure 4.1 and Table 4.3). Most of these improvements have occurred during the last three years. Only about 12,600 linear feet (25 percent of the total) was completed prior to the initiation of the current monitoring project.

The planning and construction of more than nine miles of stream restoration activity in a single watershed is a notable accomplishment. However, the completed restoration activities directly affect less than three percent of the channel network in the Muddy Creek drainage. They address only nine percent of the reach length prioritized in the MCRP's 2003 watershed plan (MCRP, 2003) as meriting NCD restoration, livestock exclusion or revegetation work (Table 4.3). These figures vary by sub-watershed, and overall are somewhat higher for the South Muddy Creek drainage than for the North Muddy Creek drainage. The GIS analysis used to develop the 2003 prioritization may overestimate the extent of restoration work necessary on tributary streams. Nonetheless, despite the extensive restoration activity to date, the vast majority of reaches identified as needing restoration has not been addressed and sediment inputs from those sites likely continue.

Table 4.2. Completed Restoration Activities Not Monitored by the Current Project

Stream Name	Sub-Watershed	Project Completion Date ¹	Project Type ²	Project Length (linear feet)
N Muddy Ck	NM-L	Fall 1999	NCD	1,000
N Muddy Ck	NM-L	Fall 1999	NCD	700
Youngs Fk	YF	Fall 2000	NCD	1,200
Youngs Fk	YF	Spring 1999	NCD	1,000
Jacktown Ck	YF	Fall 2000	LE	2,000
Goose Ck	GC	Fall 2002	REV	600
N Muddy Ck	NM-HW	Summer 2007	LE	2,300
Bobs Ck	NM-U/BC	Spring 2006	LE	1,600
Bobs Ck	NM-U/BC	Spring 2004	LE	1,500
Katy Ck	SM-M	Spring 2008	LE	2,000
Goose Ck	GC	Winter 2007	NCD	900

(1) Status as of April 2008. Work at the Katy Creek site had not been completed at the time of Year 3 monitoring.

(2) Key to Project Types: NCD = natural channel design stream restoration (includes revegetation).

REV = riparian area revegetation only.

LE = livestock exclusion (no revegetation unless otherwise specified).

Figure 4.1. Location of Completed Stream Improvement Projects in the Muddy Creek Watershed

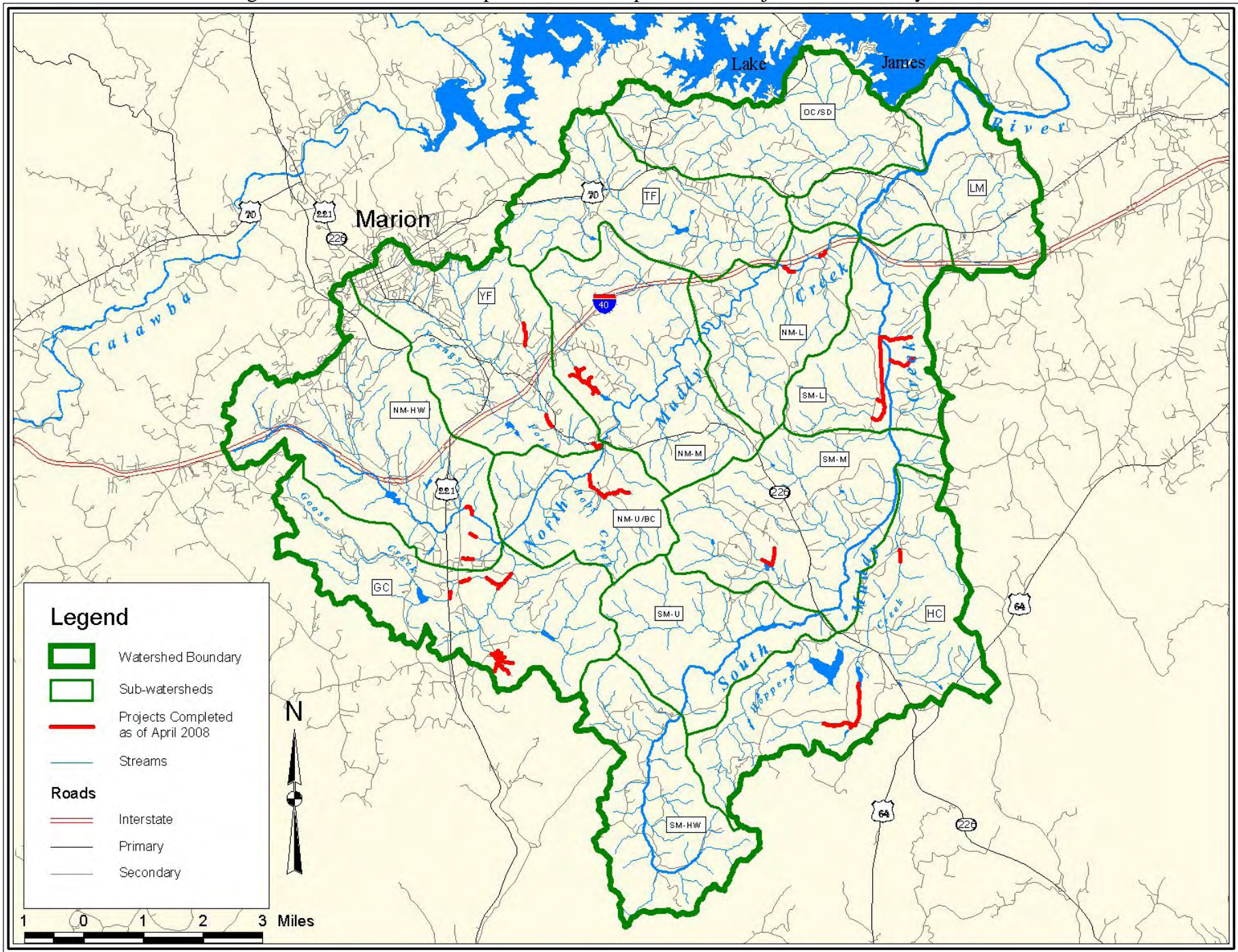


Table 4.3. Overview of Completed Restoration Project Length by Sub-Watershed

Sub-Watersheds					Stream and Restoration Data-- Individual Sub-watersheds Only			Stream and Restoration Data— Cumulative Totals for Sub-watersheds				Project Length as % of Cumulative ⁶ :	
Drainage	Name ¹	DA ² (mi ²)	Monit Site ID	Monit Site DA ² (mi ²)	Total Stream Length ³ (ft)	Priority Reach Length ⁴ (ft)	Project Length ⁵ (ft)	DA ² (mi ²)	Total Stream Length ³ (ft)	Priority Reach Length ⁴ (ft)	Project Length ⁵ (ft)	Stream Length ³	Priority Reach Length ⁴
North Muddy	N. Muddy - HW*	10.7	29	10.1	154,767	23,912	2,300	10.7	154,767	23,912	2,300	1.5%	9.6%
	Goose Ck*	9.3	27	9.1	129,416	52,432	12,300	9.3	129,416	52,432	12,300	9.5%	23.5%
	N. Muddy - Upper/Bobs	5.2	24	24.6	97,249	55,200	5,000	25.3	381,433	131,544	19,600	5.1%	14.9%
	Youngs Fork*	8.4	22	7.4	131,326	17,893	4,200	8.4	131,326	17,893	4,200	3.2%	23.5%
	N. Muddy - Middle	9.2	19	42.8	136,731	89,346	0	42.8	649,490	238,783	23,800	3.7%	10.0%
	Thompsons Fork*	7.6	18	7.4	135,023	135,023	0	7.6	135,023	135,023	0	0.0%	0.0%
	N. Muddy - Lower	5.9	16	56.3	111,539	3,524	1,700	56.3	896,052	377,330	25,500	2.8%	6.8%
South Muddy	S. Muddy - HW*	7.0	none	none	117,299	0	0	7.0	117,299	0	0	0.0%	
	S. Muddy - Upper	5.9	13	12.7	97,138	0	0	12.9	214,436	0	0	0.0%	
	Hoppers Ck*	11.0	9	9.3	167,814	52,651	8,200	11.0	167,814	52,651	8,200	4.9%	15.6%
	S. Muddy - Middle	9.5	8	33.5	155,429	44,586	2,000	33.5	537,680	97,237	10,200	1.9%	10.5%
	S. Muddy - Lower	6.3	6	39.7	112,648	36,011	14,500	39.7	650,327	133,248	24,700	3.8%	18.5%
Lower Muddy Ck	Old Catawba River*	7.4	4	6.9	121,141	0	0	7.4	121,141	0	0	0.0%	
	Lower Muddy Creek	7.3	5	98.0	119,330	40,834	0	110.7	1,786,851	551,412	50,200	2.8%	9.1%
Watershed Total								110.7	1,786,851	551,412	50,200	2.8%	9.1%

(1) Denotes hydrologically independent sub-watersheds, i.e. those not receiving drainage from upstream sub-watersheds.

(2) DA indicates drainage area.

(3) Total stream length represents stream length based upon GIS measurements using hydrography data available from BasinPro8.

(4) Priority reaches are those identified in the MCRP restoration plan (MCRP, 2003) plan for natural channel design stream restoration, riparian reforestation or livestock exclusion.

(5) Project length represents length of stream projects of all types completed prior to the initiation of Year 3 annual monitoring (July-November 2007, depending upon monitoring site). Restoration projects completed after the end of monitoring are not included. Total stream length and priority reach length (both based on GIS measurements) are likely underestimated compared to project length (field measurement).

(6) The calculation of the project length as a percentage of the cumulative priority reach length assumes that all completed projects are on priority reaches.

Section 5 Evaluation of Restoration Impacts

This section begins with a summary of the restoration impacts observed during this study (Section 5.1), followed by a presentation of the analysis used to derive those conclusions. Sections 5.2 and 5.3 outline the approach used to evaluate restoration impacts. The site-specific (Section 5.4) and broad scale (Section 5.5) impacts of stream improvement projects are then discussed and the available data presented. Estimates of overall reductions in bank erosion are presented in Section 5.6.

5.1 Summary of Impacts Observed

The current monitoring effort did not formally evaluate project implementation (e.g., by comparing existing conditions to as-built conditions, or by assessing structural stability). However, informal observation, as well as information available from funding agencies and design firms, suggests that projects are generally performing as intended.

Site-specific impacts were examined at seven reaches where stream improvement projects are complete and at three comparison reaches. The impacts observed can be summarized as follows (Table 5.1):

- Improvement in overall aquatic habitat and in bank erosion potential was evident at all natural channel design sites for which both pre-restoration and post-restoration data were available.
- The comparison sites did not generally show improvement in these parameters, increasing the likelihood that results could be attributed to the restoration efforts and not to other factors.
- Improvement in substrate parameters due to project activity was generally not evident at natural channel design sites. Depending upon the location, either improving trends were not yet evident, or there was some doubt, given site-specific circumstances, that improvement could be reasonably attributed to the stream project.
- Improvements in benthic community conditions were not evident at any site. At a number of natural channel design sites, a decline that can likely be attributed to construction-related disturbance is evident. In some cases, benthos have begun to rebound from this impact, but still had not yet recovered to the pre-project condition by the end of the monitoring period. The deepening drought in the last few years of the monitoring project is thought to be a serious complicating factor.
- Photographic evidence indicates clear improvements in stream morphology, bank stability and other characteristics at NCD sites.
- Less change is evident at the sites where improvement activities involved only livestock exclusion or riparian area revegetation. Improved stream condition at such sites is highly dependent on vegetative growth and longer-term natural processes to heal stream bank erosion and enhance habitat.

Despite reductions in bank erosion at restoration project sites, in-stream improvement at the sub-watershed and watershed scales is not yet evident. This is not surprising given the recent completion of most restoration projects and the large restoration need remaining.

Many issues complicate data interpretation at both the site level and at broader scales. These include factors as diverse as the deepening drought over the course of the monitoring period, the lack of information regarding sediment transport processes, and site-specific circumstances such as beaver activity and landowner clearing and mowing of riparian areas at those sites where easements have not been required.

Estimates of sediment inputs from bank erosion indicate that the natural channel design projects completed to date have reduced sediment inputs to Muddy Creek and its tributaries by at least 6,000 tons per year. This is the equivalent of 375 dump truck loads of sediment per year, assuming a 16 ton capacity for a typical 3-axle dump truck. This figure does not include estimates of sediment reductions from the more than 15,000 linear feet of stream where only livestock exclusion and/or revegetation activities occurred.

Table 5.1. Summary of Site-Specific Impacts of Completed Stream Improvement Projects

Station ID #	Stream Name	Project Type	Data Available (Years pre-post)	Indicator				Notes
				Habitat	Bank Erosion Potential	Benthos	Riffle Substrate	
Restoration Sites								
07	Patten Branch	NCD	1-2	Y	Y	--	NC	
10	S. Fork Hoppers Ck.	NCD, LE	1-2	Y	Y	CI	NC	
28	UT to Goose Ck.	LE	2-1	NC	NC	NC	Y*	The only post monitoring event was immediately after project completion
21	Bledsoe Branch	NCD, LE	2-1	Y	Y	NC	Y*	The only post monitoring event was immediately after project completion
25	Bobs Creek	NCD	0-3	Y	NC	NC	Y	Site impacted by beaver activity
27	Goose Creek	REV, LE	0-3	Y	NC	NC	Y*	
09	Hoppers Creek	NCD	0-3	CI	Y	CI	CI	Site impacted by post construction problems and subsequent repair
Comparison Sites								
11	S. Fork Hoppers Ck.	none	3-0	D	NC	NC	NC	
14	High Shoals Creek	none	3-0	NC	Y	NC	NC	Improvement in bank erosion potential may reflect change in transect location
17	UT to N. Muddy Ck.	none	3-0	NC	NC	--	NC	

Key to Impacts (see remainder of Section 5 for discussion):

Y = data indicate probable improvement in site condition, which can be reasonably attributed to restoration project (except Site 14).

Y* = data indicate improvement in site condition, but it is unclear that improvement should be attributed to the stream project.

D = data indicate probable decline in site condition.

CI = construction impact (data indicate likely decline in site condition due to construction, from which the site has not yet recovered).

NC = no change (data indicate that no meaningful change in site condition is probable).

Key to Project Types:

NCD = natural channel design stream restoration (includes revegetation).

REV = riparian area revegetation only

LE = livestock exclusion (no revegetation unless otherwise specified)

Notes:

Riffle substrate rating is the composite of three parameters: % embeddedness, D₅₀ and % silt-sand.

-- Data not available

5.2 Issues in Analyzing Restoration Impacts

Evaluating the effects of stream improvement projects is a complex undertaking that involves drawing conclusions about potential cause and effect relationships between restoration activities and indicators of stream quality. For a positive effect to be clearly demonstrable, several conditions must hold:

- An improvement in environmental conditions must actually have occurred;
- The improvement must be measurable and distinguishable from normal variation in conditions; and
- One must be able to attribute the observed change to the intervention as opposed to other events or circumstances.

Numerous factors, many of which are both time and scale dependent, have a bearing on these three conditions. A full review of all of the issues involved is well beyond the scope of this report. However, Appendix E provides a brief review of some of the key factors as they pertain to the Muddy Creek watershed.

In general, drawing conclusions regarding the impact of restoration activities becomes progressively more difficult as scale broadens, because the number of confounding factors increases and the task of accounting for these factors becomes more complex. The lack of information on upland sediment sources and changes in land management practices clearly limits the conclusions that can be drawn from this study, especially at scales broader than individual restoration sites.

It may be premature to expect that the impacts of restoration completed thus far in the Muddy Creek watershed will be detectable on a broad scale. It also seems unlikely that any positive trends observed at this scale could be readily attributed to stream improvement activities with any confidence. Key reasons for this include (see Appendix E):

- The limited extent of restoration completed compared to overall need;
- The limited time elapsed since the completion of most stream improvement projects;
- The high level of natural variability in those indicators most likely to be sensitive to change at the sub-watershed and watershed scales;
- Complications due to other watershed activities and sediment sources; and
- Varying hydrologic conditions during the monitoring period, most notably the worsening drought during 2006 and 2007.

This report attempts to draw the most defensible conclusions possible with the data currently available. To make a strong case that observed improvements are due to the restoration projects implemented and not to other trends or events, one must be able to rule out potential alternative explanations for the findings observed. The use of robust experimental design and statistical analysis techniques can greatly enhance the ability to do this, although obtaining sample sizes sufficient to detect statistically significant treatment effects can be prohibitively expensive. In the absence of such a design and lacking the data to conduct more sophisticated statistical analyses, this project will rely on a ‘strength of evidence’ approach. A ‘strength of evidence’ or ‘lines of evidence’ approach involves the logical evaluation of the available types (lines) of evidence in order to reach a conclusion (USEPA, 1998 and 2000).

5.3 Analysis Approach

Based on the information discussed in the previous sections of this report, the analysis of restoration impacts will be approached as follows.

5.3.1 Site Scale Impact Analysis

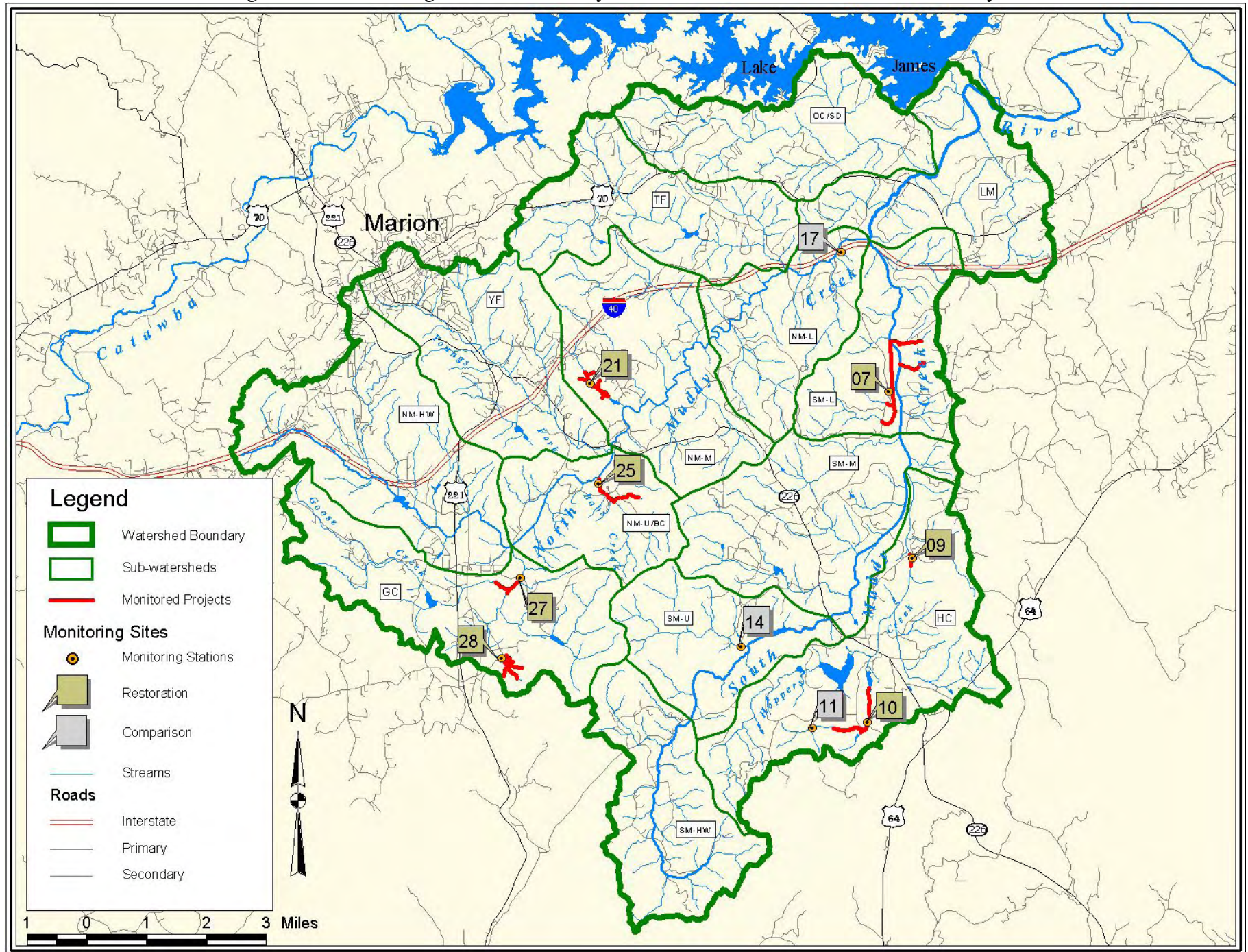
As discussed in Section 4, the analysis of site-specific restoration impacts must necessarily be limited to the seven monitoring locations at which restoration work is complete. These sites are profiled individually, with the available data reviewed for each location and site-specific circumstances evaluated. The sites include (Figure 5.1):

- Four sites with both pre and post-restoration data - Patten Branch (Site 7), South Fork Hoppers Creek (Site 10), UT to Goose Creek (Site 28) and Bledsoe Branch (Site 21).
- Three sites completed prior to the initiation of the present monitoring project – Bobs Creek (Site 25), Hoppers Creek (Site 9) and Goose Creek (Site 27). Only post-restoration data were collected at these locations, although limited pre-restoration data are available for some locations from previous assessment work.

The analysis also includes a discussion of several comparison sites. Given what is known about the eight sites that could potentially be used for comparison purposes (see Section 4), three sites seem most appropriate. These are notable for the relative stability of site management over the study period, as well as for the lack of known disturbances in their upstream drainages (based upon anecdotal information and observation during the monitoring period). None of these can be considered true reference sites. All have experienced significant impacts in the past and some are awaiting restoration. Nonetheless, these sites may be useful to help establish background trends for comparison with restored areas. The three comparison sites are (Figure 5.1):

- Site 14 (High Shoals Creek) is a reach currently relatively unaffected by ongoing activities. Surrounding land use is forest and abandoned pasture. The 2.5 square mile drainage is largely rural and appears to have experienced little change during the monitoring period, though some timber harvesting has occurred.
- Sites 11 (South Fork Hoppers Creek) and 17 (UT to South Muddy Creek) run through active pasture land and have been subject to substantial historic degradation, although little change in on-site activity has occurred during the monitoring period. Both sites drain small catchments (<0.7 square miles) where limited disturbance upstream of the site appears to have occurred over the monitoring period.

Figure 5.1. Monitoring Sites in the Muddy Creek Watershed Used for Site Scale Analysis



5.3.2 Analysis of Broader Scale Impacts

It is likely to be much more difficult to identify clear cumulative impacts at the sub-watershed and watershed scales than to identify site-specific improvements (see Appendix E). For this reason, the broader scale analysis reported here will be limited primarily to several sub-watersheds draining limited areas where the possibility of identifying changes in stream conditions and drawing conclusions about the causes of those changes appears greatest.

Six monitoring sites represent individual sub-watersheds that are hydrologically independent – that is, they do not have any upstream sub-watersheds draining into them (see Table 4.3). Two of these (Thompsons Fork-Site 18, and Old Catawba River –Site 4) have no restoration projects in their drainage. Two other sites, Goose Creek (Site 27) and Hoppers Creek (Site 4), are within reaches that were subject to restoration activity and will be reviewed in the site analysis section of this report. Two other sites remain where cumulative restoration impacts at the scale of single sub-watersheds can be readily evaluated (North Muddy Headwaters – Site 29, Youngs Fork - Site 22). The sub-watershed scale analysis reported below will therefore focus on these two sites, with Sites 4 and 18 used for comparison purposes.

There are also seven broader scale monitoring sites in the Muddy Creek drainage, as well as three sites on the Catawba River. Since it is not likely that measurable cumulative impacts will be identifiable at this scale at the present time, the analysis of broad scale impacts will be limited to two synoptic locations near the mouths of North Muddy (Site 16) and South Muddy (Site 6) Creeks.

5.4 Findings - Site Impacts

5.4.1 Comparison Sites

Monitoring data indicate that conditions were relatively stable at the three comparison sites (Table 5.2). Conductivity was fairly constant at each site, indicating no obvious changes in water quality or effects of changing stream discharge. Total aquatic habitat scores were also consistent for the most part, although there was a ten point decline in the score at Site 11 from 2005 to 2006, reflecting slightly lower scores on a number of metrics. Scores for the BEHI were also largely consistent, with differences likely reflecting measurement variability. The drop in the BEHI score for Site 14 in 2007 appears to be due to an inadvertent shift in transect location. The VASOS scores were relatively stable for the two sites for which they were available. Site 17 lacked appropriate riffle substrate and was not sampled.

Riffle substrate parameters exhibited greater variability than most other measures, consistent with the findings at the quarterly monitoring sites (Appendix F). Substrate fluctuations were greatest at Site 14 where the transects monitored were moved over the course of the study due to riffle migration. This is the largest site and thus may be most subject to upstream watershed influences. When all three sites and all substrate parameters are considered, no consistent trend in riffle substrate characteristics is apparent.

The three comparison sites are at locations where no known change in on-site management occurred during the three years of the monitoring project and where new disturbance in the upstream drainage is believed to be minimal. These sites thus represent a baseline in terms of expected change under the prevailing conditions during the monitoring period. Results at these sites provide no indication that trends should be expected in any of the parameters examined.

Table 5.2. Selected Monitoring Results for Three Small Comparison Sites

Site ID	Stream	DA (mi ²)	Date	Spec. Cond. (µmhos/cm)	Habitat Score	BEHI Avg.	VASOS Score ¹	% Riffle Embeddedness	D ₅₀ Riffle (mm)	Riffle % Silt-Sand
11	S. Fork Hoppers Ck	0.5	6/21/2005	37	55	17.8	11	50	2	51
			7/17/2006	38	45	20.3	10	65	10	37
			7/20/2007	38	45	19.2	10	70	1	53
14	High Shoals Creek	2.5	10/5/2005	36	78	26.7	9	40	12	29
			10/25/2006	37	81	24.2	11	8	9	36
			8/31/2007	39	83	19.0	8	40	15	17
17	UT to North Muddy	0.1	10/4/2005	57	30	32.7		65	1	66
			8/10/2006	58	33	28.3		80	0.71	63
			8/7/2007	54	34	31.5		100	0.33	73

(1) VASOS monitoring was not conducted at Site 17 due to lack of appropriate riffle substrate.

5.4.2 Restoration Sites with both Pre- and Post-Restoration Data

This section discusses the four sites for which both pre and post-restoration project data were collected by the MCRP: Patten Branch (Site 7), South Fork Hoppers Creek (Site 10), UT to Goose Creek (Site 28) and Bledsoe Branch (Site 21). A *project profile box* for each site is provided, summarizing pertinent information on the restoration project itself, as well as the extent of data available. ‘MCRP data’ denotes data collected by MCRP as part of the current monitoring effort. ‘Other data’ refers to comparable data available from other sources, including data from earlier MCRP assessments that can be used to compare pre and post conditions. ‘Project documents’ refers to restoration design and monitoring reports. The easement width refers to the width on each side of the stream. Design reports are available for most, though not all, natural channel design (NCD) projects. Monitoring reports are available for most NCEEP projects.

Site 7 - Patten Branch (natural channel design restoration).

Description. Patten Branch is a small tributary of South Muddy Creek. Prior to restoration it was a ditched stream dominated by sandy material (Figure 5.2a), with a bankfull width of five to seven feet and a sinuosity of 1.04 (EMHT, 2005). The surrounding land use is primarily in row crops. Objectives of the NCD project were to improve channel stability, reestablish a connection with the floodplain, and improve aquatic habitat and riparian condition. A new meandering channel (sinuosity of 1.4) was constructed and the old channel abandoned and filled with spoil material (EMHT, 2007). Riparian areas were planted with native trees and shrubs, both live stake and bare root.

The restoration plan noted that some sediment deposition would be expected in this stream even after the completion of restoration: “The existing channel bed is dominated by coarse sand and the restored stream channel will likely continue to experience sand deposits that will create bars and riffles and define the bed form of the channel. The bed form in the restored stream channel will not be static and will reshape within the bottom of the channel over time. Constructed pools and riffles would likely become impacted by the anticipated sand deposition.” (p. 13, EMHT 2005). The initial annual monitoring conducted by the designer in April 2007 indicated that the channel was largely functioning as intended, although minor bank sloughing and scour had occurred within and upstream of the monitored reach, generally on meanders (EMHT, 2007). Stem counts in the riparian area were less than acceptable and additional plantings are planned.

Analysis. The initial post-restoration monitoring conducted by MCRP in 2006 occurred about six months following completion of construction. At this time a significant improvement in aquatic habitat was evident (Table 5.3), due to improved channel morphology, improved extent and diversity of in-stream habitat, and decreased bank erosion. Bank stability, as measured by

<p><i>Profile: Site 7 - Patten Branch:</i></p> <ul style="list-style-type: none">> Drainage Area – 2.1 sq mi> Project Type - natural channel design> Project Information:<ul style="list-style-type: none">• Design firm – EMHT, Inc.• Project funder - NCEEP• Project length – 14,500 ft.• Completion date – spring 2006• Easement width -30 ft.> Project Documents:<ul style="list-style-type: none">• EMHT, 2005; EMHT, 2007> Evaluation Data Available:<ul style="list-style-type: none">• MCRP data - 1 yr. pre, 2 yr. post• Other data - none> Restoration Effects Observed:<ul style="list-style-type: none">• Habitat – improvement• Bank stability – improvement• Benthos – no data• Substrate – no change
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the BEHI, increased substantially, from scores in the 20s (considered by Rosgen, 1996 and 2001, to represent moderate erosion potential) to levels <10 (very low erosion potential). Although changes in bank morphology were evident in 2006, the BEHI score did not improve until 2007, when vegetation became better established.

Substrate has not improved to date. Pebble counts were generally conducted in runs since riffles did not exist on most occasions. Post-construction monitoring conducted by the project designer has not thus far included riffles for this reason (EMHT, 2007). The stream channel at this site was constructed with sufficient gradient to establish riffle morphology, but coarse material to provide substrate for riffles was not imported. Such material is expected to move into the reach over time. Given this fact, as well as the concerns expressed in the design document regarding continued sediment deposition, lack of improvement in substrate characteristics is not surprising.

Data are not available to evaluate the response of the biological community, as riffle substrate adequate to conduct VASOS monitoring did not exist in two of the three years. The reason for the drop in conductivity in 2007 is not apparent, although this measurement was taken after an extended period of extreme drought conditions. Corn is grown in the area surrounding much of the restoration site, and changes in fertilization practices could also be a factor.

Figures 5.2b and 5.2c illustrate the reestablished channel sinuosity, bank stability and floodplain access, but with sandy substrate instead of the desired gravel substrate.

Table 5.3. Patten Branch (Site 7): MCRP Data, 2005-2007

Date	Period	Spec. Cond. (µmhos/cm)	Habitat Score	BEHI Avg.	VASOS Score ¹	% Riffle Embedded. ¹	D ₅₀ Riffle (mm)	Riffle % Silt-Sand
10/4/2005	Pre	42	17	23.0			0.14	100
11/10/2006	Post	46	46	22.5	7		0.079	100
11/7/2007	Post	16	41	8.8			0.094	100

(1) Some data not collected due to lack of appropriate substrate.

Figure 5.2. Photos – Patten Branch (Site 7)



5.2a. Substrate prior to restoration.



5.2b. Channel pattern and riparian vegetation six months after restoration.



5.2c. Approximately 18 months after restoration.

Site 10 - South Fork Hoppers Creek (natural channel design restoration).

Description. Prior to restoration, this channelized stream was moderately incised in some areas, though incision was limited by the presence of coarse bed material and grade control from culvert crossings (Buck, 2005). Sinuosity was 1.03, although the stream was starting to redevelop meanders in places. Riparian condition was considered to be poor and cattle had access to portions of the project area. Bank erosion contributed considerable sediment to the stream.

The intent of the restoration was to construct a meandering channel through an agricultural field, reconnect the stream to its floodplain and enhance in-stream habitat diversity (improved riffles and pools). In-stream structures installed included root wads, cover logs and log veins, constructed riffles and rock cross vanes. Native vegetation was replanted in the riparian area. The banks were stabilized with live stakes, bare root plantings and transplants. Riverine wetland functions were restored to adjacent hydric soil areas by filling drainage ditches. Fencing was installed to exclude livestock from the portion of the stream where they had access. Construction was completed in May 2006, with unspecified repairs made in October 2006.

Analysis. More data are available at this location than for other sites, including considerable monitoring information available from the project design firm. Visual observations by the design firm the year following completion of construction indicated that all structures were functioning as designed and were holding elevation grade (Baker, 2007). Riffles, pools and meanders were stable.

Even though the MCRP’s initial post-restoration monitoring (2006) was conducted only four months following restoration, habitat scores improved dramatically; some additional improvement was seen in 2007 (Table 5.4). Habitat improvements are due to increased habitat extent and diversity of habitat types, better riffle and pool morphology and increased bank stability. Baker Engineering collected pre- and post-construction habitat data using the same NCDWQ protocol used by MCRP. The sites monitored were located within the extent of the restoration project, but not within the portion of the project that served as the MCRP study reach. Habitat improved at the Baker Engineering sites following restoration, while it decreased slightly at a reference site located upstream of the project boundary (Table 5.5).

Bank erosion potential (Table 5.4) was markedly reduced, improving from a score of about 34 (indicating high erosion potential) to less than 20 (low potential). An assessment conducted by the design firm as part of the restoration feasibility evaluation and design process (Buck, 2005) estimated that, prior to restoration, approximately 600 tons of sediment entered the stream each

Profile: Site 10 – South Fork Hoppers Creek:

- > Drainage Area – 1.3 sq mi
- > Project Type - natural channel design, livestock exclusion
- > Project Information:
 - Design firm – Buck (now Baker) Engineering.
 - Project funder - NCEEP
 - Project length – 7,200 ft.
 - Completion date – May 2006, repair in Oct. 2006
 - Easement width - 30 ft.
- > Project Documents:
 - Buck Engineering, 2005
 - Baker Engineering, 2007
- > Evaluation Data Available:
 - MCRP data - 1 yr. pre, 2 yr. post, including Duke benthos data
 - Other data - :pre and post data from Baker Engineering., including benthos and pebble count
- > Restoration Effects Observed:
 - Habitat – improvement
 - Bank stability – improvement
 - Benthos –decline
 - Substrate – no change

year from the 5,300 linear feet of stream assessed, or about 113 tons/yr per 1,000 linear feet. This contrasts with a soil loss of <5 tons/yr per 1,000 linear feet in stable streams studied in Buncombe County (Buck, 2005).

Table 5.4. South Fork Hoppers Creek (Site 10): MCRP Data, 2005-2007

Date	Period	Spec. Cond. (µmhos/cm)	Habitat Score	BEHI Avg.	VASOS Score	% Riffle Embedded.	D ₅₀ Riffle (mm)	Riffle % Silt-Sand
6/23/2005	Pre	41	37	33.7	11	60	8	44
8/9/2006	Post	43	64	17.0	4	65	22	44
7/4/2007	Post	41	70	14.2	8	40	2	51

Table 5.5. South Fork Hoppers Creek (Site 10): Baker Engineering Habitat Data

Date	Period	Location ¹	Habitat Score
1/11/05	Pre	# 1	94
1/17/07	Post	# 1	84
1/11/05	Pre	# 2	74
1/16/07	Post	# 2	86
1/12/05	Pre	# 3	53
1/16/07	Post	# 3	82

(1) Monitoring locations: # 1 – reference, upstream of restoration project; # 2 - within restoration project but upstream of study reach; # 3 - within restoration project but downstream of study reach. Source: Buck, 2005, and Baker, 2007.

Riffle substrate data collected by MCRP do not show any clear trend, (Table 5.4), nor do substrate data collected by Baker at several cross sections within the MCRP study reach (Table 5.6). The lack of substrate improvement may be due to the fact that sufficient time had not elapsed to allow sediment transport at the sites to fully stabilize. Additionally, considerable bank erosion continues at Site 11, located upstream, where design of a NCD project is currently underway. Sediment transport into Site 10 will likely continue until restoration of the upstream reach has been carried out. Figure 5.3 indicates improvement in channel morphology and bank stability.

Table 5.6. South Fork Hoppers Creek (Site 10): Baker Engineering Substrate Data

Date	Period	Location	D ₅₀ Riffle (mm)	Riffle % Silt-Sand
11/10/04	Pre	XS 13	19	14
11/6/07	Post	XS 3	0.69	57
11/6/07	Post	XS 5	7.6	36

Notes: Locations represent riffle locations selected by Baker and are located within the MCRP study reach. Substrate data calculated by Equinox from Baker pebble count data (Buck, 2005, and Baker, 2007).

Considerable data on benthic communities are available for Site 10. In addition to the VASOS data collected by Equinox (Table 5.4), Duke Energy sampled this site using NCDWQ’s standard qualitative method (Table 5.7). Baker Engineering sampled the site as well, using NCDWQ’s

Qual4 method, which utilizes a simpler sampling procedure than the standard qualitative method (Table 5.7). Baker's sampling sites, while located within the extent of the restoration project, were not within the portion of the project that served as the MCRP study reach.

All three sets of benthic community data indicate a sharp decline in the benthic community for the first monitoring event following the completion of restoration. This is very likely due to the disturbance associated with channel construction activity. Even in the second year following restoration (2007), the community had not yet returned to pre-construction levels, although some improvement occurred. The deepening drought in 2007 may also be a contributor to the slow recovery. The benthic community at the Baker reference site, located upstream of Site 10 but below Site 11, was relatively stable, with some minor deterioration that may be due to the drought. As a whole, the benthic data indicate that where substantial channel disturbance is necessary during restoration, improvement of the benthic community in response to enhanced habitat conditions is not likely to be immediate, especially in small streams where opportunities for recolonization from upstream may be limited.

Table 5.7. South Fork Hoppers Creek (Site 10): Baker Engineering and MCRP Benthic Monitoring Data

Metric	Baker 1 (reference)		Baker 2 (upstream)		Baker 3 (downstream)		MCRP Site		
	Pre 1/11/05	Post 1/17/07	Pre 1/11/05	Post 1/16/07	Pre 1/12/05	Post 1/16/07	Pre 7/26/05	Post 7/19/06	Post 7/23/07
Total Taxa Richness	36	50	31	43	27	40	62	57	67
EPT Taxa Richness	23	21	21	15	14	13	26	13	16
Total Biotic Index	3.15	3.47	3.03	5.58	3.03	5.53	4.65	6.6	6.53
Total Habitat Score	94	84	74	86	53	82	37	64	70

Notes:

Buck reach 3 (Buck 2005) and Baker reaches 6 and 7 (Baker 2007) roughly correspond to the MCRP study reach.

Baker benthic sampling locations: #1 – reference, upstream of restoration project.

#2 - within restoration project but upstream of study reach.

#3 - within restoration project but downstream of study reach.

The MCRP site is located between Baker #2 and #3.

Benthic sampling at this site was conducted by Duke Energy on the dates indicated in table.

Habitat assessments were conducted by Equinox Environmental on: 6/23/05; 8/9/06; 7/4/07.

Benthic macroinvertebrate sampling methods: Baker used NCDWQ's Qual4 method, Duke Energy used NCDWQ's standard qualitative method.

Figure 5.3. Photos – South Fork Hoppers Creek (Site 10)



5.3a. Channel condition prior to restoration.



5.3b. Channel morphology and riparian vegetation in August 2006, approximately three months following restoration.



5.3c. Riparian vegetation in July 2007, approximately fourteen months following restoration.

Site 28. Unnamed Tributary to Goose Creek (livestock exclusion).

Description. Prior to the exclusion project, cattle had unrestricted access to the entire length of this site. Cattle trails were common in the riparian area and stream banks were impacted by hoof shear in some areas. Woody vegetation was limited and heavily browsed. The stream improvement project involved the provision of providing an alternative water source and construction of fencing to keep livestock out of the riparian area (Figure 5.4). There is currently no livestock access to the stream, although a stream crossing is provided. No bank repair or riparian plantings was carried out, but a 10-15 foot wide riparian area adjacent to the stream is being allow to revegetate naturally. This project was funded through EQIP and was officially considered complete in the fall of 2007, but exclusion of livestock was effective earlier in 2007, prior to the final monitoring event.

Analysis. No trends are evident in aquatic habitat quality, bank erosion potential or benthic community condition (Table 5.8). This is not surprising, as livestock exclusion projects do not involve any direct remediation of stream physical conditions (see Section 4). Fencing had been in place for only a few months prior to the final monitoring event, leaving only a limited period for natural processes to improve conditions following the cessation of direct livestock impacts. Improvement in riffle substrate is evident in the final year for all three substrate measures, and in the second year for two measures. However, it is not clear that this can be attributed to the stream project. Removal of direct livestock activity within the stream could potentially result in substrate improvement, but there is no reason to expect this in 2006, when cattle had not yet been fenced out. The apparent changes in substrate may be due to natural variation in substrate condition (see Appendix F), weather variations during the study period (Section 2), or to year-to-year changes in livestock activity.

Profile: Site 28 – UT to Goose Ck:

- > Drainage Area – 0.4 sq mi
- > Project Type - livestock exclusion
- > Project Information:
 - Design firm – none
 - Project funder – NRCS EQIP
 - Project length – 7,600 ft.
 - Completion date – fall 2007
 - Easement width -none
- > Project Documents:
 - none
- > Evaluation Data Available:
 - MCRP data - 2 yr. pre, 1 yr. post
 - Other data - none
- > Restoration Effects Observed:
 - Habitat – no change
 - Bank stability – no change
 - Benthos – no change
 - Substrate – possible improvement

Table 5.8. UT Goose Creek (Site 28): MCRP Data, 2005-2007¹

Date	Period	Spec. Cond. (µmhos/cm)	Habitat Score	BEHI Avg.	VASOS Score	% Riffle Embedded.	D ₅₀ Riffle (mm)	Riffle % Silt-Sand
7/27/2005	pre	67	76	20.8	6	45	11	46
8/3/2006	pre	73	71	22.0	11	50	13	39
9/11/2007	post	74	73	21.8	9	15	24	30

(1) LE project not officially complete until fall of 2007, but fencing was installed and livestock effectively excluded during 2007 prior to final monitoring event.

Figure 5.4. Photos – UT Goose Creek (Site 28)



5.4a. Fencing installed on the site, June 2008.



5.4b. The stream channel in June 2008, approximately ten months following livestock exclusion.

Site 21. Bledsoe Branch (natural channel design, livestock exclusion).

Description. This small tributary to North Muddy Creek was incised and subject to severe bank erosion due to both livestock access and the lack of riparian vegetation (Figures 5.5a and 5.5b). The restoration project involved excavating a floodplain and resloping of the banks to improve stability. Channel work had been completed only weeks prior to the final monitoring event, though livestock had been removed from the area some time before. A conservation easement was not required.

Analysis. Aquatic habitat improved substantially at this site following construction of the new channel (Table 5.9), due primarily to the improved extent and diversity of in-stream habitat, more extensive riffle and pool areas, and improved bank stability. The BEHI score declined somewhat, improving from the high erosion potential category to the moderate category. This improvement primarily reflects the change in bank morphology of the reconstructed stream. Woody vegetation had not yet been planted at the time of the 2007 monitoring. Bank erosion potential is likely to continue improving with vegetative growth. No trend was evident in benthic community condition.

- Profile: Site 21 –Bledsoe Branch:*
- > Drainage Area – 0.7 sq mi
 - > Project Type - natural channel design, livestock exclusion
 - > Project Information:
 - Design firm – NRCS
 - Project funder – NRCS
 - Project length – 5,000 ft.
 - Completion date – fall 2007
 - Easement width - none
 - > Project Documents:
 - none
 - > Evaluation Data Available:
 - MCRP data - 2 yr. pre, 1 yr. post
 - Other data - none
 - > Restoration Effects Observed:
 - Habitat – improvement
 - Bank stability – improvement
 - Benthos – no change
 - Substrate – possible improvement

Prior to the restoration, the NRCS estimated that eroding banks in this reach contributed 330 tons of sediment/year to the stream (Alan Walker, NRCS. Personal communication 4/21/08), or about 100 tons/year per 1,000 linear feet.

The evidence for substrate improvements is unclear. All three riffle substrate parameters improved from 2006 to 2007, which could theoretically reflect the effect of restoration. However, two of the three indicators (median particle size and percent silt/sand) also indicated improvement from 2005 to 2006, prior to the restoration project.

Figures 5.5c and 5.5d show post-project stream channel conditions, including improved bank stability and floodplain access.

Table 5.9. Bledsoe Branch (Site 21): MCRP Data, 2005-2007

Date	Period	Spec. Cond. (µmhos/cm)	Habitat Score	BEHI Avg.	VASOS Score	% Riffle Embedded.	D ₅₀ Riffle (mm)	Riffle % Silt-Sand
7/27/2005	pre	62	42	38.5	8	50	2	57
9/12/2006	pre	66	35	34.9	11	65	10	33
12/18/2007	post	65	68	27.9	9	25	20	29

Figure 5.5. Photos – Bledsoe Branch (Site 21)



5.5a. Pre-restoration bank erosion, in meandering section Sept. 2006.



5.5b. Pre-restoration condition in straight section.



5.5c. Post-restoration, illustrating improved bank condition.



5.5d. Post-restoration riffle area.

5.4.3 Restoration Sites Completed Prior to Monitoring Project

Restoration of three reaches (Sites 25, 27 and 9) was completed prior to the initiation of the monitoring project—two in 2002, three years prior to initiation of monitoring, and one in 2004. Project monitoring at these sites thus cannot document changes from pre-restoration conditions, but only whether conditions have been improving over the period studied. As discussed earlier, it is probably reasonable to expect some aspects of channel and riparian conditions to improve for a number of years following restoration.

Site 25. Bobs Creek (natural channel design).

Description: A tributary of North Muddy Creek, Bobs Creek was an incised channelized stream prior to restoration. Bank erosion was considerable and there was virtually no woody riparian vegetation. The site was used for hay production, although cattle had previously been pastured there. The restoration project reestablished a sinuous channel with stable banks and an appropriate floodplain. Woody vegetation was planted in the riparian zone, although no easement was required by the project funder at the time. Site improvement has been hindered because the landowner has been cutting some riparian vegetation. Land adjacent to the site is still used for hay production. MCRP collected quarterly data at this site.

Beaver activity impacted the site during the monitoring period. Beaver dams, which were removed by the land owner and then rebuilt by the beavers on numerous occasions, impounded portions of the reach and caused sediment accumulation.

Analysis. While no pre-restoration data on bank stability are available, photographic evidence and anecdotal information indicate that severe erosion was a major problem (Figure 5.6a). Erosion potential at this site was low throughout the monitoring period, reflecting the stable channel morphology established by the restoration project (Table 5.10). On average, habitat scores were higher during 2007 (avg. score of 59) than during the previous two years (avg. score of 53).

Benthic community condition, as assessed by either the VASOS (Table 5.10) or NCDWQ methods (Table 5.11), showed some initial improvement, followed by decline. The reason for this is unclear, though it may be due to worsening drought conditions or to the intermittent beaver activity. Riffle substrate improved somewhat: average embeddedness was 43 percent in 2007, but 54 percent in earlier years; percent silt-sand was 30 percent in 2007 compared to 37 percent in previous years.

<p><i>Profile: Site 25 –Bobs Creek:</i></p> <ul style="list-style-type: none">> Drainage Area – 2.1 sq mi> Project Type - natural channel design> Project Information:<ul style="list-style-type: none">• Design firm – NCSU• Project funder – NC Division of Water Resources• Project length – 1,900 ft.• Completion date – spring 2002• Easement width –none> Project Documents:<ul style="list-style-type: none">• none> Evaluation Data Available:<ul style="list-style-type: none">• MCRP data - 0 yr. pre, 3 yr. post, plus quarterly data and Duke benthos data• Other data – limited MCRP data for 2001> Restoration Effects Observed:<ul style="list-style-type: none">• Habitat – improvement• Bank stability – no change• Benthos – no change• Substrate – improvement
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Based on the photographic evidence (Figure 5.6), there is little doubt that sediment production has been drastically reduced at this site. Bank stability is much improved, a more natural channel morphology has been established and some improvement in aquatic habitat has occurred. Major changes likely occurred in the reach prior to the initiation of the current monitoring project. Additional improvements have been limited by beaver activity in the reach. The cutting of riparian vegetation has also limited the improvement in habitat scores.

Table 5.10. Bobs Creek (Site 25): MCRP Data, 2001-2007

Date	Period	Spec. Cond. (µmhos/cm)	Habitat Score	BEHI Avg.	VASOS Score	% Riffle Embedded.	D ₅₀ Riffle (mm)	Riffle % Silt-Sand
3/19/2001	pre	NA	NA	NA	NA	NA	16	30
11/15/2001	post	NA	NA	NA	NA	NA	9	36
6/21/2005	post	41	48	13.5	9	55	2	50
3/8/2006	post	39	54	11.9	12	35	5	42
6/13/2006	post	45	58	12.4	11	45	12	25
9/15/2006	post	48	52	12.7	10	65	8	42
12/7/2006	post	41	55	12.2	6	70	10	35
2/22/2007	post	35	61	16.3	12	35	7	37
5/10/2007	post	37	55	15.0	7	45	14	29
8/6/2007	post	46	62	13.2	8	50	9	36
11/14/2007	post	33	59	16.2	6	40	12	19

Notes: March and Nov. 2001 data were based on pebble counts conducted by MCRP prior to the current project using a similar protocol. Figures reported are averages of results for six riffle sites.

Nov. 2001 monitoring was conducted just after channel work was complete but prior to riparian plantings.

NA-- indicates data on the specified parameter were not collected.

Table 5.11. Bobs Creek (Site 25): Benthic Community Data Collected by Duke Energy

Metric	Year		
	2005	2006	2007
Total EPT Taxa	23	31	24
Biotic Index	4.69	5.20	5.34
Bioclassification	Good-Fair	Good-Fair	Good-Fair

Notes: Data collected using the NCDWQ Standard Qualitative Method. The Division of Water Quality would likely not assign a bioclassification to this site because it falls below the 3 square mile drainage area threshold generally used to apply the rating system. For sites <3 mi² DWQ would normally consider a condition that appears to reflect a G-F to indicate that the stream is not impaired (NI), but the agency would not apply a formal bioclassification.

Figure 5.6. Photos – Bobs Creek (Site 25)



5.6a. Pre-restoration (2002).



5.6b. Two years post-restoration (2004).



5.6c. Four years post-restoration (2006).



5.6d. Six years post-restoration (2008).

Site 27. Goose Creek (livestock exclusion, revegetation).

Description. Goose Creek at this location runs through hay and pasture land. The stream was previously channelized, though banks had been graded to a relatively low angle. Woody riparian vegetation was virtually nonexistent prior to the project. Bank erosion was minimal for the most part and seldom severe, due to generally modest bank angles and dense grass (Figure 5.7a). The improvements implemented at this site consisted primarily of woody vegetation plantings along the graded bank face and in a narrow flat area extending out from the top of the bank. Livestock were fenced out of the portion of the project area to which they had access. No easement was required for this project and the riparian area consists of only a narrow fringe above the top of bank. Livestock continued to have access to a portion of Goose Creek upstream of this site. A livestock exclusion project was implemented there (Site 28) during 2007, but for most if not all of the monitoring period livestock activity in this upstream reach continued. Site 27 drains over 9 square miles and was intended to serve as a synoptic site for the sub-watershed.

Profile: Site 27 –Goose Creek:

- > Drainage Area – 9.1 sq mi
- > Project Type – revegetation, livestock exclusion
- > Project Information:
 - Design firm – none
 - Project funder – USEPA, others
 - Project length – 3,200 ft.
 - Completion date – fall 2002
 - Easement width -none
- > Project Documents:
 - none
- > Evaluation Data Available:
 - MCRP data - 0 yr. pre, 3 yr. post
 - Other data - none
- > Restoration Effects Observed:
 - Habitat – improvement
 - Bank stability – no change
 - Benthos – no change
 - Substrate – possible improvement

Analysis. Initial monitoring occurred three years after the completion of restoration. The overall habitat score at this site increased by 22 points from 2005 to 2006 (Table 5.12), reflecting improved ratings for the extent and diversity of in-stream habitat, as well as better bank stability due to improved vegetative cover. An additional, though smaller, habitat improvement occurred in 2007, reflecting in part better stream shading due to the growing vegetation (Figure 5.7). There was essentially no change in the BEHI or VASOS scores at this site.

All riffle substrate parameters improved from 2005 to 2006. It is not readily apparent how this relates to the restoration work, although the reach did include some eroding banks that could have gradually stabilized due to replanting in 2002 and removal of livestock from the riparian area. The site drains a large area, however, and changes in land use within the sub-watershed also may be a factor. The extent of developed land in this sub-watershed increased by more than one-third between 1998 and 2005 (see Section 2); more recent information is not available.

Table 5.12. Goose Creek (Site 27): MCRP Data, 2005-2007

Date	Period	Spec. Cond. (µmhos/cm)	Habitat Score	BEHI Avg.	VASOS Score	% Riffle Embedded.	D ₅₀ Riffle (mm)	Riffle % Silt-Sand
8/4/2005	post	49	31	16.2	7	55	9	43
8/10/2006	post	50	53	15.5	8	40	21	22
9/11/2007	post	51	60	16.9	8	40	23	26

Figure 5.7. Photos – Goose Creek (Site 27)



5.7a. Pre-restoration (2002).



5.7b. One and one-half years (1 growing season) post-restoration.



5.7c. Four years post-restoration (2006).



5.7d. Riparian zone (center of photo) in 2008.

Site 9. Hoppers Creek (natural channel design).

Description. Hoppers Creek at this location was a straight (sinuosity = 1.02) channelized stream prior to restoration (Clemmons and Burgess, 2004). The stream was entrenched (average bank height ratio of 3.16) with very limited floodplain access. The high stream banks were often failing (Figure 5.8a), serving as a significant sediment source. Riffles were rare, substrate heterogeneity was limited and excessive sand was evident in runs and pools. The riparian area consisted of an abandoned pasture on one bank, and a wide mowed path on the other.

The objective of this project was to restore the reach to a stable morphology, thereby improving floodplain access, in-stream habitat and riparian condition. A new meandering channel was constructed and bankfull bench established to create a floodplain. Banks and riparian areas were seeded and planted in trees and shrubs using native species. In-stream structures included log vanes and root wads. Channel construction was completed in the fall of 2004, although riparian plantings were not completed until the next year. Some bank sloughing and structure failure subsequently occurred, resulting in sediment inputs into the reach. Repairs were made in 2006.

Analysis. Aquatic habitat conditions declined in 2006 from the previous year (Table 5.13). This decline may be due to in-stream activity necessary to repair the banks and structures, which occurred just a few months prior to the monitoring. Improvement occurred by 2007, but habitat remains poor overall. Benthic community condition also declined in 2006, probably for the same reason, and rebounded in 2007. Bank erosion potential declined from 2006 to 2007, as vegetative cover became more widely established.

Pre-restoration data collected by the NCWRC in 2004 are available for two riffle substrate indicators (Table 5.13). It appears that riffle substrate declined due to construction and subsequent repair activities. Substrate indicators began to improve by 2007, although they have still not returned to pre-construction levels. The reach immediately upstream from the project is highly incised with ongoing bank erosion.

Overall, existing data do not indicate significant improvement since 2005, though quantitative comparisons with pre-project conditions are not possible since pre-restoration data are largely lacking. Photographic evidence (Figure 5.8) indicates that sediment input reductions are extremely likely. Bank pins installed by the MCRP in 2001 on a typical bend in the reach indicated an average bank recession of 13.9 inches over a 26 month period (6.4 inches/yr). Based on the bank pin data, pre-restoration soil loss as high as 260 tons/1,000 linear feet may have occurred annually in this reach, where typical bank heights were about ten feet.

<p><i>Profile: Site 9 –Hoppers Creek:</i></p> <ul style="list-style-type: none">> Drainage Area – 9.3 sq mi> Project Type - natural channel design> Project Information:<ul style="list-style-type: none">• Design firm – NCWRC• Project funder – CWMTF, NCWRC• Project length – 1,000 ft.• Completion date – fall 2004, repairs in 2006• Easement width –30 ft. minimum> Project Documents:<ul style="list-style-type: none">• Clemmons and Burgess, 2004> Evaluation Data Available:<ul style="list-style-type: none">• MCRP data - 0 yr. pre, 3 yr. post• Other data –limited pre data from the NCWRC> Restoration Effects Observed:<ul style="list-style-type: none">• Habitat – decline• Bank stability – improvement• Benthos – decline• Substrate – decline

This site was intended to serve as a synoptic station for the Hoppers Creek sub-watershed, and potential impacts from other activities within the nine square mile drainage complicate interpretation of site specific impacts. Though the sub-watershed supports significant agricultural activity, substantial development has occurred recently (doubling of developed acreage from 1998 to 2005). Development trends during the period of the current monitoring project are unknown. Additionally, NCD restoration was underway during 2005 and 2006 at Site 10, some distance upstream. However, a flood control impoundment located between Sites 9 and 10 served to insulate Site 9 from activities at the upstream site, as well as some other watershed activities.

Table 5.13. Hoppers Creek (Site 9): MCRP and NCWRC Data, 2004-2007

Date	Period	Spec. Cond. (μ mhos/cm)	Habitat Score	BEHI Avg.	VASOS Score	% Riffle Embedded.	D ₅₀ Riffle (mm)	Riffle % Silt-Sand
2004	pre	NA	NA	NA	NA	NA	10.6	20
6/23/2005	post	13	32	26.7	9	10	0.14	79
7/17/2006	post	25	23	25.4	4	80	0.096	87
7/20/2007	post	52	35	19.8	8	40	8	41

Notes: 2004 data collected by the NCWRC as part of restoration design (Clemmons and Burgess, 2004). Other data collected by MCRP.

NA indicates data collection not planned.

Figure 5.8. Photos – Hoppers Creek (Site 9)



5.8a. Pre-restoration, showing erosion and incised channel (2004).



5.8b. Approximately nine months following channel construction, but prior to riparian planting and bank repair (January 2005).



5.8c. April 2006, two years post-restoration.



d. June 2008, four years post-restoration.

5.5 Findings - Sub-Watershed and Watershed Scale Impacts

Two sub-watershed scale monitoring stations (Hoppers Creek, Site 9; Goose Creek, Site 27) that were subject to on site restoration activities were discussed previously. This section will focus primarily on four additional sub-watersheds that are hydrologically independent (i.e. do not have any upstream sub-watersheds draining into them). Additionally, synoptic sites near the downstream end of North and South Muddy Creeks will be discussed. Data for the remaining broad-scale sites are available in Appendix B.

5.5.1 Cumulative Impacts at Sub-Watershed Stations

The North Muddy Headwaters sub-watershed (Site 29) and the Youngs Fork sub-watershed (Site 22) are the most developed in the Muddy Creek watershed. In 2005, 30 percent of the Youngs Fork sub-watershed was developed, as was 23 percent of the North Muddy Headwaters sub-watershed. Between 1998 and 2005, urban uses in these sub-watersheds increased by 4 percent and 11 percent, respectively.

The Thompsons Fork (Site 18) and Old Catawba River (Site 4) sub-watersheds, where no restoration projects have yet been implemented, are used here for comparison purposes. While less developed than the North Muddy or Youngs Fork catchments, they experienced larger increases (14-15 percent) in developed land between 1998 and 2005.

The habitat score at the Youngs Fork site increased substantially in 2007, while habitat scores in North Muddy Creek showed a slight improving trend (Table 5.14). Habitat in Thompsons Fork improved significantly in 2006. It is difficult to attribute changes in habitat in the restoration sub-watersheds to stream improvement projects in light of the increase at Thompsons Fork and the fact that there is no reason to expect many habitat metrics to be highly sensitive to upstream restoration activities.

The limited extent of restoration completed upstream of these sites is also a factor. Little stream improvement has been completed in the North Muddy Creek Headwaters sub-watershed -- 2,300 linear feet in a sub-watershed with over 154,000 feet of stream and 24,000 feet of stream identified as a priority for restoration (see Section 4). A portion of the completed restoration work is on a tributary downstream of the monitoring site. About 4,200 linear feet of restoration has been completed in the Youngs Fork sub-watershed, though most of this is downstream of the monitoring site.

Neither the benthic community score (VASOS) nor the three parameters representing riffle substrate conditions, show a clear trend at the North Muddy Creek or Youngs Fork sites. As discussed earlier, the riffle substrate scores tend to have high natural variability. Bank erosion potential at the sub-watershed scale sites is not likely to be impacted by upstream stream improvement projects.

Table 5.14. Summary of MCRP Monitoring Data at Four Sub-Watershed Scale Sites

Site ID	Stream	DA ¹ (mi ²)	Date	Spec. Cond. (µmhos/cm)	Habitat Score	BEHI Avg.	VASOS Score	% Riffle Embedded.	D ₅₀ Riffle (mm)	Riffle % Silt-Sand
Restoration Sub-watersheds										
22	Youngs Fork	7.4	8/25/2005	109	65	30.8	4	65	11	38
			8/9/2006	106	58	23.7	5	75	17	20
			8/22/2007	112	80	26.8	5	50	19	19
29	North Muddy Creek	10.1	10/28/2005	65	55	28.7	5	70	8	39
			9/28/2006	68	61	29.8	4	75	10	31
			9/5/2007	72	64	24.7	4	65	8	34
Comparison Sub-watersheds										
4	Old Catawba River	6.9	8/25/2005	66	84	21.7	5	40	35	34
			10/25/2006	68	80	15.3	5	30	26	25
			9/17/2007	72	82	17.9	5	5	58	15
18	Thompsons Fork	7.4	10/12/2005	62	39	29.9	7	25	7	47
			8/10/2006	72	54	31.2	9	35	6	45
			9/17/2007	73	53	35.2	7	35	6	44

(1) DA=drainage area at monitoring site.

5.5.2 Impacts in the North Muddy and South Muddy Drainages

For the two monitoring sites located at the downstream end of North Muddy Creek (Site 16) and South Muddy Creek (Site 6), quarterly monitoring data are available for most parameters. These data provide no evidence of improvement at either site (see Table 5.15 for listing of data and Appendix F for graphs and statistics).

- Aquatic habitat shows no change in North Muddy Creek and appears to have declined slightly in South Muddy Creek.
- Riffle substrate variables such as embeddedness and median substrate size show tremendous variation, but no temporal trend is discernable.
- Benthic community data collected by Duke Energy at these sites (Section 3) indicate a bioclassification of Good-Fair at each site for the entire 2005-2007 period, though there was some variability in individual metrics.

As discussed in Appendix E, there are a number of reasons one would expect improvement at these sites to be difficult to discern. While about 25,000 linear feet of stream improvement projects have been completed in each drainage, this is only a small fraction of identified stream improvement needs. Additionally, both sites drain sizable areas (about 57 square miles for North Muddy Creek and 40 square miles for South Muddy Creek) impacted by a variety of upland activities. South Muddy Creek was also impacted by the release of sediment from an upstream impoundment during dam maintenance activities. Given these factors, as well as the expected time lag in sediment transport and the declining streamflows over the course of the monitoring period, it is not surprising that any positive impacts from stream improvement projects would be difficult to detect at this time.

Table 5.15. Summary of MCRP Monitoring Data at Synoptic Sites on North Muddy Creek (Site 16) and South Muddy Creek (Site 6)

Site ID	Stream	DA (mi ²)	Date	Spec. Cond. (µmhos/cm)	Habitat Score	BEHI Avg.	VASOS Score ¹	% Riffle Embedded. ¹	D ₅₀ Riffle (mm)	Riffle % Silt-Sand
16	North Muddy Creek	56.3	10/4/2005	76	52	28.2	5	30	7	43
			3/8/2006	68	59	28.2	6	50	7	43
			6/13/2006	79	43	28.1	5	50	9	33
			10/4/2006	81	56	27.7	6	70	14	23
			12/19/2006	63	46	31.1	6	65	8	41
			3/8/2007	61	42	31.8	9	35	10	32
			5/30/2007	72	46	30.0	9	60	13	31
			8/7/2007	81	54	30.1	6	60	14	32
			12/13/2007	77	49	30.8	5	40	15	20
6	South Muddy Creek	39.7	10/20/2005	49	52	25.2	8	50	2	50
			3/8/2006	46	48	21.1	10	80	0.45	69
			6/13/2006	51	51	22.0	8	50	1	65
			10/4/2006	52	40	22.1	6	70	2	54
			12/19/2006	45	36	20.4	8	80	7	45
			3/8/2007	43	42	21.1		40	6	45
			6/19/2007	47	41	19.4			0.88	56
			8/22/2007	50	47	20.2	5	60	9	33
			12/13/2007	47	40	21.5			0.4	70

(1) Some data not collected due to lack of appropriate riffle substrate.

5.6 Estimates of Bank Erosion Prevented

Estimates of pre-restoration bank erosion inputs, developed by restoration designers, are available for two NCD sites studied during this project. These indicated soil loss of 113 tons/yr/1,000 linear feet and 100 tons/yr/1,000 linear feet for Sites 10 and 21, respectively, compared to an estimated 5 tons/yr/1,000 linear feet for stable streams (Buck, 2005). Assuming pre-restoration soil loss at these two sites is typical of all NCD sites completed in the watershed (approximately 34,400 linear feet, as discussed in Section 4), the total sediment loss avoided by all completed NCD projects can be estimated as 2,669 tons per year (see Table 5.16 for methods).

This estimate is clearly overly conservative, however. The two sites noted above are located on small streams and typical bank heights are about five feet. Some restored reaches are located on streams with much higher banks, where it would be logical to expect the soil loss per 1,000 linear feet to be substantially greater. Two restored reaches in the lower North Muddy Creek (NM-L) sub-watershed (see Table 4.2), not monitored by this project, had an estimated pre-restoration soil loss of over 1,000 tons per year for their 1,200 foot length (Harman and Jennings, 2002). Bank pin data for Site 9 (Hoppers Creek), where banks were ten feet high, indicate likely soil loss of about 260 tons/yr/1,000 linear feet.

Given this, a more reasonable estimate of the extent of bank soil loss prevented by completed NCD projects is probably at least 6,000 tons per year. This can be visualized as 375 dump truck loads of sediment per year, assuming a 16 ton capacity for a typical 3-axle dump truck. This estimate does not include any sediment inputs prevented by the more than 15,000 linear feet of projects completed that involve only livestock exclusion and/or revegetation.

5.7 Catawba River Fisheries

In 1941, the NCWRC began a catchable-sized stocked trout fishery in the 2 km immediately below Lake James at the Bridgewater dam. In 1996, the NCWRC began fingerling stocking efforts in the remaining 27 km between Lake James and Lake Rhodhiss. Previous studies in the 1990s found few trout or other game fish in this lower section (Besler, 2003). Seasonal low dissolved oxygen levels and poor habitat due to sand and silt deposition, believed to largely come from Muddy Creek, were proposed as potential reasons. Data were collected in 2000-2002 to evaluate the results of the new stocking effort. Results suggest that annual stockings since 1996 have established and are maintaining a brown trout population in the lower 27 km section (Besler, 2003). Some reproductive and nursery habitat exists.

The NCWRC has conducted fisheries monitoring below Lake James in more recent years, but these data have not yet been compiled. Anecdotal information indicates that fishing conditions are improving, that insect diversity has increased and that larger trout are being caught (Squeak Smith, Trout Unlimited. Personal communication 6/16/2008). Over the past ten years prolific mayfly and caddisfly hatches have been observed in the Catawba River downstream of its confluence with Muddy Creek.

Table 5.16. Calculation of Soil Loss Prevented by Completed Restoration Projects

<i>Pre-Restoration Estimates:</i>
1. Pre restoration soil loss for sites in the watershed is assumed to be 106 tons/yr/1,000 linear feet, the average of the two estimates available.
2. Data on the overall pre-restoration length of NCD project reaches are not available. It is clear that this length will be less than the post-restoration length, since unrestored reaches are usually rather straight and are transformed into more sinuous (and therefore longer) reaches during restoration.
3. A sinuosity of 1.3 to 1.4 is typical for restored reaches in the Muddy Creek watershed. Assuming that typical pre-restoration sinuosity is 1.05 and typical post-restoration sinuosity is 1.35, the estimated pre-restoration length of the 34,400 feet of restored stream is 26,800 linear feet.
4. At 106 tons/yr/1,000 linear feet, the pre-restoration soil loss from this length of unrestored stream is 2,841 tons/yr.
<i>Post-Restoration Estimates:</i>
1. Post-restoration soil loss from bank erosion is assumed to be 5 tons/yr/1,000 linear feet, based on the results of evaluations of stable streams in Buncombe County (Buck, 2005).
2. 34,400 linear feet of natural design restoration projects have been completed thus far in the Muddy Creek watershed (see Tables 4.1 and 4.2).
3. The expected loading from stream bank erosion from these completed restoration sites = (34.4 thousand linear feet) x (5 tons/yr/1,000 linear feet) = 172 tons/yr.
<i>Soil Loss Prevented:</i>
Sediment inputs prevented by the NCD projects can be calculated as the difference between the pre- and post-restoration loads: 2,841 tons/yr - 172 tons/yr = 2,669 tons/yr.

Section 6 Discussion and Recommendations

Over the 10 years between 1998 and 2008, stream improvement projects were completed on 50,200 feet of stream in the Muddy Creek watershed. About two thirds of this length has involved natural channel design (NCD) stream restoration, with the remainder some combination of livestock exclusion and riparian revegetation projects. Three-quarters of this work has been completed within the past three years. This is a considerable accomplishment, representing the substantial work and commitment of the organizations making up the MCRP, as well as the contributions of many funding agencies and local property owners.

The three-year monitoring project discussed in this document represents the efforts of the MCRP to evaluate the impact of these restoration activities. While this report marks the end of the monitoring project, the MCRP continues to work actively in the watershed. The MCRP has been the catalyst for nine ongoing projects, representing over 30,000 linear feet of stream work, in the design or construction phase. Furthermore, because of the planning work conducted by the MCRP and the effectiveness of the MCRP in initiating on the ground restoration, NCEEP has designated Muddy Creek as a Priority Watershed for implementing stream and wetland mitigation projects. Under contract to NCEEP, Equinox has recently completed a landowner outreach effort that identified approximately 34,000 feet of potential NCD restoration projects in the watershed.

The vision of the MCRP is ultimately for improved ecological conditions, including aquatic habitat and biological communities, in Muddy Creek and its tributaries, as well as in the Catawba River below its confluence with Muddy Creek. The partnership seeks to improve water quality and habitat such that a more natural sediment regime is established, all streams in the watershed support their intended uses, and pollution from Muddy Creek no longer serves as a stressor to the trout population in the Catawba River.

The partnership's activities are not limited to the types of stream improvement projects discussed in this report. The group is spearheading a watershed planning project for Corpening Creek/Youngs Fork, which is considered impaired by the NCDWQ due to toxic pollutants and other stressors. The plan will identify the sources of the pollutants and make recommendations to improve water quality. Funded by the North Carolina Clean Water Management Trust Fund and the USEPA Section 319 Program, this effort will be completed in 2009.

Implementation of stream improvement projects on Muddy Creek and its tributaries is still a work in progress, and the same can be said for efforts to evaluate the effects of those projects. The remainder of this section discusses some of the implications of the current monitoring project for the MCRP and makes recommendations for the future, focusing primarily on sediment issues.

6.1 Discussion

The planning and implementation of stream restoration projects in the Muddy Creek watershed is proceeding at a rapid pace, assuring that many sediment inputs from stream bank sources will continue to be addressed. However, a number of issues merit additional attention:

1. Further documentation of the effects of restoration projects;
2. Review of the sediment problems in a broader context, including sediment sources other than bank erosion;
3. Addressing fecal coliform bacteria contamination.

6.1.1 Documentation of Restoration Effects

While the findings reported earlier in this document indicate a number of positive outcomes from the stream improvement efforts completed to date, including the prevention of approximately 6,000 tons of sediment inputs per year, additional work remains in order to adequately quantify the effects of these projects. For example, most restoration projects in the watershed have been completed only recently. Due to the time lag in sediment transport, it is very likely that much of the sediment reduction at the project site level is not yet reflected by conditions further downstream. Additionally, some site improvements, such as those dependent upon vegetative growth, did not have sufficient time to fully develop.

A number of other limitations are inherent in the approach used in this project, as discussed earlier in this report:

- Sediment transport was not measured directly.
- Monitoring at most sites was limited to a series of three annual observations, which is insufficient to clearly identify trends in parameters subject to wide fluctuations.
- Information on watershed activities and land use change during the monitoring period was not systematically collected, providing little information to aid the understanding of changes in stream condition at the sub-watershed and watershed scales. While fairly recent information on land cover change was available, it did not cover the monitoring period.

Finally, it is clear that the MCRP has established considerable momentum in implementing stream restoration projects, and the extent of restoration work carried out in the near future will be substantial. Within five years, the length of completed projects is likely to be more than double what it is today.

All of these factors point to the need for additional monitoring to track the impacts of stream improvement activities over at least the next decade. The early NCD projects in the watershed were funded through a variety of mechanisms, most of which required limited, if any, post-project monitoring. However, most current and future NCD projects are likely to be funded by the NCEEP, which currently requires annual monitoring using a standardized methodology over a five-year post-project period. The MCRP resources will be best used by building on this effort, and focusing primarily on monitoring of watershed and sub-watershed scale impacts. Livestock exclusion and revegetation projects are a possible exception, as little documentation is generally available for such projects.

6.1.2 Sediment Transport and Sources

While the MCRP has focused considerable attention on documenting sediment reductions, and other improvements related to the stream projects implemented, it is important not to lose site of

the bigger picture. Visual assessment and historic total suspended solids sampling provide a strong indication that sediment loads have been very high. However, overall sediment loads have not been accurately determined, nor have the full range of potential sources been evaluated.

A computer simulation model, referred to as WARMF (Watershed Analysis Risk Management Framework), was developed for the watershed by Systech Engineering, in conjunction with Duke Energy and the Electric Power Research Institute. This model predicted suspended sediment loads from the Muddy Creek watershed of 1,435,000 kg/day, or over 577,000 tons per year (Chen et al, 2004). The assumptions used in model development are difficult to evaluate, however, and the accuracy of the resulting estimates is not clear. An earlier appraisal tentatively estimated the sediment load at about 20,000 tons per year (MCRP, 2003). This estimate was based upon the limited information available in the 1990s, and is likely too low. Neither of the available estimates attempted to account for bedload transport, which may be considerable in this watershed.

Stream bank erosion is clearly an important sediment source in the watershed. However, the MCRP has thus far focused little attention on sediment contributions from upland areas. Potential upland sources include improperly managed forestry and agricultural operations, eroding roads, land clearing for development, and unstabilized portions of existing developed areas. Whether their magnitude is increasing or decreasing is not known. Since increased loading from upland areas could offset any reductions from stream improvement projects, this is an important issue.

At this point there are a number of important questions that cannot be answered:

- Have overall sediment loads from the watershed been increasing or decreasing?
- If stream restoration projects are successful, how long might it take before loads to the Catawba River are substantially reduced?
- Will increases in upland inputs offset sediment reductions from stream bank sources?

Drought conditions in western North Carolina, including McDowell County, progressively worsened during the monitoring period. This very likely limited sediment transport in the Muddy Creek watershed and complicates the interpretation of results.

Data on trends in the status of biological communities in North and South Muddy Creeks are ambiguous. Monitoring by NCDWQ indicates some improvement from 2002 to 2007, though the agency suspects some of this may be due to the recent low precipitation and streamflows (with resultant lower inputs of nonpoint source pollutants). Benthic community monitoring conducted by Duke indicates improved conditions in 2005-2007 compared to 2001-2004, but not compared to 2000.

6.1.3 Fecal Coliform Bacteria

The monitoring conducted during this study has documented that contamination from fecal coliform bacteria is significant and widespread. Bacterial contamination is not an ecological concern for Muddy Creek and the Catawba River (this contamination does not directly impact aquatic organisms), although it is possible that nutrients and oxygen-consuming waste that enters

streams along with the bacteria could be problematic. However, the frequent violations of the North Carolina water quality standard for fecal coliform are clearly a public health concern that should be addressed.

The current study was not designed to provide information on the source of this contamination, and little such information is available. Livestock waste is the likely source at some locations, though livestock access to streams has been greatly reduced or eliminated in many areas through the efforts of agricultural agencies and the MCRP. Straight-piping or other sources of domestic waste are another possible source, although no systematic assessment of the magnitude of this problem has been made. Wildlife and domestic animals are other potential sources.

6.2 Recommendations

The MCRP recognizes that watershed improvement is an iterative process involving multiple cycles of planning and assessment, implementation of management measures and evaluation of outcomes. The following recommendations are made to address the issues discussed above.

6.2.1 Documentation of Restoration Effects

- The MCRP should seek to establish a long-term monitoring effort to evaluate conditions in North and South Muddy Creeks related to sediment impacts. If resources allow, this effort should be extended to selected sub-watersheds.
 - Monitoring stations should be established at the lower end of North and South Muddy Creeks, near the confluence of those streams.
 - Physical monitoring should focus on parameters likely to be sensitive to changes in sediment supply, including substrate size distribution and aquatic habitat.
 - Physical monitoring should be conducted every three years over a fifteen-year period, for a total of six monitoring events. It is likely that numerous restoration projects will be implemented over the next five to ten years. Because of this, as well as the time lag between project implementation and downstream improvements, a long monitoring period is essential.
 - If resources allow, consideration should be given to the collection of suspended sediment samples using single stage samplers, supplemented by manual collection of grab samples during selected storm events. While grab samples will not generally provide an accurate measurement of overall suspended sediment concentrations, over time they could potentially provide an indication of whether concentrations are increasing or decreasing.
 - If suspended sediment sampling is conducted, stage recorders should be installed at the monitoring sites to allow estimation of stream discharge and development of stage-discharge relationships. Stage recorders would also facilitate documentation of the time of sample collection (for single stage samplers).
- Future evaluations of NCD site impacts should build on the required monitoring being conducted for NCEEP projects. Post-project data will eventually be available for these locations. After reviewing the data available from the NCEEP monitoring, the MCRP should determine whether additional data collection is warranted at selected sites to fill any information gaps that remain.

- Since projects that involve only livestock exclusion or revegetation are generally not evaluated by funding agencies, it would be beneficial for the MCRP to obtain funding that would allow it to collect some pre- and post-project information for selected project sites.

6.2.2 Sediment Transport and Sources

- Areas in need of channel restoration, revegetation or livestock exclusion were evaluated in 2000 and 2001 for inclusion in the Muddy Creek watershed plan (MCRP, 2003). It is time for a reappraisal of those priorities. The MCRP should review the original assessment data in light of stream improvement work completed or anticipated and reestablish priorities, undertaking additional field data collection and GIS assessment if necessary.
- Little information is available on the extent of sediment inputs from upland areas and whether those sources have been increasing or decreasing. The MCRP should conduct an assessment of upland sediment inputs to address both of these issues. The source areas covered by this assessment should include sites undergoing active land disturbance, existing developed areas, agricultural land, and silvicultural operations.
- Periodically updated land cover data will be a useful component of the two recommendations immediately above. Land cover data should be updated approximately every five years.
- While a robust estimate of overall sediment transport in the Muddy Creek watershed could be useful, the technical complexity and expense of the monitoring effort necessary to construct such an estimate is beyond the scope of activity that the MCRP can undertake at the present time. The MCRP should instead focus its monitoring resources on documenting stream conditions, especially as they relate to the implementation of stream improvement projects.

6.2.3 Fecal Coliform Bacteria

- The MCRP should share data on fecal coliform bacteria standards violations with NCDWQ and encourage the agency to include the affected streams on the 303(d) list (impaired waters list).
- The MCRP should work with local governmental agencies and the NCDWQ to identify sources of fecal coliform and should cooperate with NCDWQ in developing a TMDL (total maximum daily load) and restoration plan.

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Appendices

MUDDY CREEK RESTORATION PARTNERSHIP

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Appendix A

Members of the MCRP Technical Committee

Members of the Muddy Creek Restoration Partnership Technical Committee

Jim Borawa, Supervisor, Watershed Enhancement Group – N.C. Wildlife Resources Commission

Andy Brown, President and Environmental Planner – Equinox Environmental, Inc.

Tom Kenney, Lands Protection – Foothills Conservancy of North Carolina

Dan McClure, Coordinator - Carolina Lakes Resource Conservation and Development Council

Steve Melton, Field Biologist – Equinox Environmental, Inc.

Albert Moore, District Conservationist – USDA Natural Resources Conservation Service

Dan Smith – N.C. Cooperative Extension Service, McDowell County

Michael “Squeak” Smith, Board of Trustees – Trout Unlimited

Gene Vaughan, Senior Scientist - Duke Energy Corporation

Appendix B

Compilation of Project Stream Data

Notes for Tables B.1 and B.2

- Site ID refers to the ID numbers given in Table 1.1 and Figure 1.2 of main text
- BEHI = Bank Erosion Hazard Index
- D_{50} = median riffle particle size from pebble count
- % silt-sand = % silt + % sand from pebble count
- VASOS = Virginia Save Our Streams benthic macroinvertebrate protocol
- Temp = water temperature
- DO = dissolved oxygen
- Sp Cond = specific conductance (conductivity in $\mu\text{mhos/cm}$ adjusted to 25°C)
- Some observations are missing due to lack of appropriate riffles (e.g. VASOS) or water quality field meter malfunction.

Table B.1. Summary of Annual Monitoring Data Collected by Equinox Environmental in the Muddy Creek Watershed

Site ID	Stream	Date	Habitat Score	% Embeddedness	BEHI Average	D ₅₀ Riffle (mm)	% Silt-Sand	VASOS Score	Temp (°C)	DO (mg/L)	Sp Cond (µmhos/cm)
1	Catawba River	9/30/2005	76	60	22.9	3	42		19.4	8.4	59
1	Catawba River	7/28/2006	82	60	18.5	28	25		20.9		62
1	Catawba River	10/10/2007	94	25	17.8	59	15		18.8	9.2	54
2	Catawba River	9/30/2005	77	50	22.3	11	39		19.8	8.3	58
2	Catawba River	7/28/2006	82	55	19.1	57	24		21.2		61
2	Catawba River	10/10/2007	92	30	13.9	67	14		18.0	8.6	51
3	Catawba River	9/30/2005	87	60	19.2	10	40		21.1	7.6	47
3	Catawba River	7/28/2006	82	55	18.7	64	23	10	17.6		51
3	Catawba River	10/10/2007	95	25	18.3	88	17		20.0	8.8	54
4	Old Catawba River	8/25/2005	84	40	21.7	35	34	5	21.2	5.7	66
4	Old Catawba River	10/25/2006	80	30	15.3	26	25	5	9.5	9.5	68
4	Old Catawba River	9/17/2007	82	5	17.9	58	15	5	17.6	7.1	72
5	Muddy Creek	10/25/2005	33	70	26.1	0.99	72		11.1	9.6	65
5	Muddy Creek	10/25/2006	28	45	28.6	0.39	73		7.5	13.2	68
5	Muddy Creek	9/17/2007	33		27.1		0		16.3	12.2	52
6	South Muddy Creek	10/20/2005	52	50	25.2	2	50	8	15.3	9.1	49
6	South Muddy Creek	10/4/2006	40	70	22.1	2	54	6	15.8	8.0	52
6	South Muddy Creek	8/22/2007	47	60	20.2	9	33	5	24.2	8.1	50
7	Patten Branch	10/4/2005	17		23.0	0.14	100		15.9	8.7	42
7	Patten Branch	11/10/2006	46		22.5	0.079	100	7	14.8	8.5	46
7	Patten Branch	11/7/2007	41		8.8	0.094	100		10.4	11.5	16
8	South Muddy Creek	10/28/2005	59	45	26.5	42	27	7	11.5	10.2	46
8	South Muddy Creek	1/26/2007	58	40	24.7	47	17	10	5.4	11.7	43
8	South Muddy Creek	11/14/2007	57	55	23.4	37	33	7	11.6	10.7	34
9	Hoppers Creek	6/23/2005	32	10	26.7	0.14	79	9	21.8	7.5	13
9	Hoppers Creek	7/17/2006	23	80	25.4	0.096	87	4	58.3		25
9	Hoppers Creek	7/20/2007	35	40	19.8	8	41	8	23.8	8.1	52
10	S Fork Hoppers Ck.	6/23/2005	37	60	33.7	8	44	11	17.3	8.5	41
10	S Fork Hoppers Ck	8/9/2006	64	65	17.0	22	44	4	25.4		43
10	S Fork Hoppers Ck	7/4/2007	70	40	14.2	2	51	8	20.6	9.0	41
11	S Fork Hoppers Ck	6/21/2005	55	50	17.8	2	51	11	15.5	8.4	37
11	S Fork Hoppers Ck	7/17/2006	45	65	20.3	10	37	10	20.1		38
11	S Fork Hoppers Ck	7/20/2007	45	70	19.2	1	53	10	20.4	8.0	38
12	South Muddy Creek	10/20/2005	42	75	23.0	2	59	10	17.6	8.6	44
12	South Muddy Creek	8/2/2006	42	65	20.0	6	34	7	22.6		49
12	South Muddy Creek	10/3/2007	42		21.8		0	6	18.4	8.9	46

(Table continued on next page)

Table B.1. Continued.

Site ID	Stream	Date	Habitat Score	% Embeddedness	BEHI Average	D ₅₀ Riffle (mm)	% Silt-Sand	VASOS Score	Temp (°C)	DO (mg/L)	Sp Cond (µmhos/cm)
13	South Muddy Creek	10/5/2005	93	35	18.6	2	53	5	18.2	9.1	43
13	South Muddy Creek	9/15/2006	86	40	21.8	0.46	59	8	18.0	8.4	46
13	South Muddy Creek	7/20/2007	84	40	21.8	46	23	8	22.5	9.4	44
14	High Shoals Creek	10/5/2005	78	40	26.7	12	29	9	18.0	8.8	36
14	High Shoals Creek	10/25/2006	81	8	24.2	9	36	11	10.6	8.9	37
14	High Shoals Creek	8/31/2007	83	40	19.0	15	17	8	21.1	8.0	39
15	Ut to South Muddy	10/25/2005	75	40	23.4	21	29	10	11.5	9.6	44
15	Ut to South Muddy	9/12/2006	77	55	21.0	17	32	12	19.9		48
15	Ut to South Muddy	8/7/2007	80	40	23.8	1	54	11	24.3	7.2	49
16	North Muddy Creek	10/4/2005	52	30	28.2	7	43	5	18.5	7.8	76
16	North Muddy Creek	10/4/2006	56	70	27.7	14	23	6	16.9	8.1	81
16	North Muddy Creek	8/7/2007	54	60	30.1	14	32	6	23.0	8.0	81
17	Ut to North Muddy	10/4/2005	30	65	32.7	1	66		18.6	7.1	57
17	Ut to North Muddy	8/10/2006	33	80	28.3	0.71	63		23.6		58
17	Ut to North Muddy	8/7/2007	34	100	31.5	0.33	73		22.2	7.3	54
18	Thompsons Fork	10/12/2005	39	25	29.9	7	47	7	20.2	8.7	62
18	Thompsons Fork	8/10/2006	54	35	31.2	6	45	9	25.4		72
18	Thompsons Fork	9/17/2007	53	35	35.2	6	44	7	20.4		73
19	North Muddy Creek	11/8/2005	84	25	23.7	16	43	5	12.8	10.8	69
19	North Muddy Creek	9/27/2006	79	45	21.5	20	35	5	17.0	8.3	84
19	North Muddy Creek	8/22/2007	83	40	21.9	32	25	5	23.5	7.7	100
20	Big Camp Branch	8/4/2005	45	25	28.7	8	41	10	21.5	7.7	54
20	Big Camp Branch	9/27/2006	39	40	39.0	8	28	12	16.3	8.4	57
20	Big Camp Branch	10/3/2007	42	40	26.8	9	28	8	17.7	9.7	55
21	Bledsoe Branch	7/27/2005	42	50	38.5	2	57	8	19.6	4.3	62
21	Bledsoe Branch	9/12/2006	35	65	34.9	10	33	11	17.5		66
21	Bledsoe Branch	12/18/2007	68	25	27.9	20	29	9	7.6	11.2	65
22	Youngs Fork	8/25/2005	65	65	30.8	11	38	4	20.5	8.2	109
22	Youngs Fork	8/9/2006	58	75	23.7	17	20	5	23.5		106
22	Youngs Fork	8/22/2007	80	50	26.8	19	19	5	23.5	9.1	112
23	Jacktown Creek	10/12/2005	60	55	31.4	14	39	6	17.6	9.2	90
23	Jacktown Creek	11/10/2006	46	70	29.5	10	35	7	15.8	7.9	91
23	Jacktown Creek	11/7/2007	59	50	30.2	3	49	8	10.1	11.4	33
24	North Muddy Creek	6/23/2005	71	35	22.4	20	23	5	21.5	7.8	52
24	North Muddy Creek	8/3/2006	69	35	21.3	25	11	7			
24	North Muddy Creek	8/31/2007	64	30	25.8	25	5	7	21.8	9.3	62

(Table continued on next page)

Table B.1. Continued.

Site ID	Stream	Date	Habitat Score	% Embeddedness	BEHI Average	D ₅₀ Riffle (mm)	% Silt-Sand	VASOS Score	Temp (°C)	DO (mg/L)	Sp Cond (µmhos/cm)
25	Bob's Creek	6/21/2005	48	55	13.5	2	50	9	18.4	8.4	41
25	Bob's Creek	9/15/2006	52	65	12.7	8	42	10	17.8	8.7	48
25	Bob's Creek	8/6/2007	62	50	13.2	9	36	8	21.6	8.1	46
27	Goose Creek	8/4/2005	31	55	16.2	9	43	7	22.9	9.3	49
27	Goose Creek	8/10/2006	53	40	15.5	21	22	8	25.6		50
27	Goose Creek	9/11/2007	60	40	16.9	23	26	8	22.7	8.6	51
28	Ut to Goose Creek	7/27/2005	76	45	20.8	11	46	6	24.8	6.7	67
28	Ut to Goose Creek	8/3/2006	71	50	22.0	13	39	11	23.5		73
28	Ut to Goose Creek	9/11/2007	73	15	21.8	24	30	9	22.7	7.4	74
29	North Muddy Creek	10/28/2005	55	70	28.7	8	39	5	10.8	10.1	65
29	North Muddy Creek	9/28/2006	61	75	29.8	10	31	4	17.3	7.5	68
29	North Muddy Creek	9/5/2007	64	65	24.7	8	34	4	21.6	8.7	72

Table B.2. Summary of Quarterly Monitoring Data Collected by Equinox Environmental in the Muddy Creek Watershed

Site ID	Stream	Season	Date	Habitat Score	% Embeddedness	BEHI Average	D ₅₀ Riffle (mm)	% Silt-Sand	VASOS Score	Temp (°C)	DO (mg/L)	Sp Cond (µmhos/cm)
6	South Muddy Creek	Fall	10/20/2005	52	50	25.2	2	50	8	15.3	9.1	49
6	South Muddy Creek	Winter	3/8/2006	48	80	21.1	0.45	69	10	8.8	7.9	46
6	South Muddy Creek	Spring	6/13/2006	51	50	22.0	1	65	8	19.5		51
6	South Muddy Creek	Fall	10/4/2006	40	70	22.1	2	54	6	15.8	8.0	52
6	South Muddy Creek	Fall	12/19/2006	36	80	20.4	7	45	8	8.6	11.3	45
6	South Muddy Creek	Winter	3/8/2007	42	40	21.1	6	45		9.4	10.2	43
6	South Muddy Creek	Spring	6/19/2007	41		19.4	0.88	56		20.0	8.6	47
6	South Muddy Creek	Summer	8/22/2007	47	60	20.2	9	33	5	24.2	8.1	50
6	South Muddy Creek	Fall	12/13/2007	40		21.5	0.4	70		11.2	9.9	47
13	South Muddy Creek	Fall	10/5/2005	93	35	18.6	2	53	5	18.2	9.1	43
13	South Muddy Creek	Winter	3/16/2006	87	40	19.5	20	39	8	12.0	6.5	41
13	South Muddy Creek	Spring	6/14/2006	80	30	18.5	12	43	7	22.2		44
13	South Muddy Creek	Summer	9/15/2006	86	40	21.8	0.46	59	8	18.0	8.4	46
13	South Muddy Creek	Fall	12/7/2006	82	50	21.8	0.65	59	7	7.2	10.3	40
13	South Muddy Creek	Winter	3/7/2007	78	70	21.7	0.33	70	9	11.0	9.3	35
13	South Muddy Creek	Spring	5/30/2007	77	10	21.5	39	27	10	21.5	9.4	41
13	South Muddy Creek	Summer	7/20/2007	84	40	21.8	46	23	8	22.5	9.4	44
13	South Muddy Creek	Fall	11/13/2007	82	30	20.6	75	16	8	11.3	10.7	31
15	Ut to South Muddy	Fall	10/25/2005	75	40	23.4	21	29	10	11.5	9.6	44
15	Ut to South Muddy	Winter	3/16/2006	71	50	20.5	19	33	12	12.5	9.8	41
15	Ut to South Muddy	Spring	6/14/2006	84	30	16.1	17	30	12	18.0		46
15	Ut to South Muddy	Summer	9/12/2006	77	55	21.0	17	32	12	19.9		48
15	Ut to South Muddy	Fall	12/18/2006	76	45	24.4	11	37	9	7.2	11.6	38
15	Ut to South Muddy	Winter	2/22/2007	81	10	19.5	23	30	10	12.0	9.1	39
15	Ut to South Muddy	Spring	5/10/2007	81	35	22.3	26	23	12	19.4	7.9	43
15	Ut to South Muddy	Summer	8/7/2007	80	40	23.8	1	54	11	24.3	7.2	49
15	Ut to South Muddy	Fall	12/13/2007	84	35	25.2	30	20	9	12.8	8.5	43
16	North Muddy Creek	Fall	10/4/2005	52	30	28.2	7	43	5	18.5	7.8	76
16	North Muddy Creek	Winter	3/8/2006	59	50	28.2	7	43	6	8.6	11.7	68
16	North Muddy Creek	Spring	6/13/2006	43	50	28.1	9	33	5	20.7		79
16	North Muddy Creek	Fall	10/4/2006	56	70	27.7	14	23	6	16.9	8.1	81
16	North Muddy Creek	Fall	12/19/2006	46	65	31.1	8	41	6	9.7	11.4	63
16	North Muddy Creek	Winter	3/8/2007	42	35	31.8	10	32	9	9.0	10.8	61
16	North Muddy Creek	Spring	5/30/2007	46	60	30.0	13	31	9	19.1	9.1	72
16	North Muddy Creek	Summer	8/7/2007	54	60	30.1	14	32	6	23.0	8.0	81
16	North Muddy Creek	Fall	12/13/2007	49	40	30.8	15	20	5	10.8	11.2	77

(Table continued on next page)

Table B.2. Continued.

Site ID	Stream	Season	Date	Habitat Score	% Embeddedness	BEHI Average	D ₅₀ Riffle (mm)	% Silt-Sand	VASOS Score	Temp (°C)	DO (mg/L)	Sp Cond (µmhos/cm)
19	North Muddy Creek	Fall	11/8/2005	84	25	23.7	16	43	5	12.8	10.8	69
19	North Muddy Creek	Winter	3/16/2006	83	55	20.5	2	52	6	10.2	7.3	71
19	North Muddy Creek	Spring	6/13/2006	79	20	19.7	11	40	7	21.7		80
19	North Muddy Creek	Fall	9/27/2006	79	45	21.5	20	35	5	17.0	8.3	84
19	North Muddy Creek	Fall	12/18/2006	71	50	23.4	12	32	7	8.9	10.1	63
19	North Muddy Creek	Winter	3/7/2007	82	13	25.1	14	39	8	8.8	10.3	61
19	North Muddy Creek	Spring	6/19/2007	76	50	23.9	26	28	7	21.3	9.0	81
19	North Muddy Creek	Summer	8/22/2007	83	40	21.9	32	25	5	23.5	7.7	100
19	North Muddy Creek	Fall	12/18/2007	74	30	25.3	37	32	6	2.5		80
25	Bob's Creek	Summer	6/21/2005	48	55	13.5	2	50	9	18.4	8.4	41
25	Bob's Creek	Winter	3/8/2006	54	35	11.9	5	42	12	11.4	4.9	39
25	Bob's Creek	Spring	6/13/2006	58	45	12.4	12	25	11	18.7		45
25	Bob's Creek	Summer	9/15/2006	52	65	12.7	8	42	10	17.8	8.7	48
25	Bob's Creek	Fall	12/7/2006	55	70	12.2	10	35	6	7.5	10.0	41
25	Bob's Creek	Winter	2/22/2007	61	35	16.3	7	37	12	8.5	10.0	35
25	Bob's Creek	Spring	5/10/2007	55	45	15.0	14	29	7	16.6	8.0	37
25	Bob's Creek	Summer	8/6/2007	62	50	13.2	9	36	8	21.6	8.1	46
25	Bob's Creek	Fall	11/14/2007	59	40	16.2	12	19	6	11.5	10.5	33

Note: Cells shaded in grey indicate annual sampling dates for each site. Other dates represent supplemental quarterly sampling events.

Table B.3. Fecal Coliform Monitoring Results in the Muddy Creek Watershed, 2005-2007

B.3.1. 2005

Site ID	Stream Name	Date	Fecal Coliform (col/100/ml)
6	South Muddy Creek	9/6/2005	170
6	South Muddy Creek	9/14/2005	300
6	South Muddy Creek	9/19/2005	240
6	South Muddy Creek	9/21/2005	280
6	South Muddy Creek	9/28/2005	170
9	Hoppers Creek	9/6/2005	300
9	Hoppers Creek	9/14/2005	280
9	Hoppers Creek	9/19/2005	170
9	Hoppers Creek	9/21/2005	130
9	Hoppers Creek	9/28/2005	220
12	South Muddy Creek	9/6/2005	220
12	South Muddy Creek	9/14/2005	1600
12	South Muddy Creek	9/19/2005	130
12	South Muddy Creek	9/21/2005	280
12	South Muddy Creek	9/28/2005	170
16	North Muddy Creek	9/6/2005	170
16	North Muddy Creek	9/14/2005	240
16	North Muddy Creek	9/19/2005	240
16	North Muddy Creek	9/21/2005	240
16	North Muddy Creek	9/28/2005	300
22	Youngs Fork	9/6/2005	170
22	Youngs Fork	9/14/2005	500
22	Youngs Fork	9/19/2005	50
22	Youngs Fork	9/21/2005	130
22	Youngs Fork	9/28/2005	130
25	Bobs Creek	9/6/2005	130
25	Bobs Creek	9/14/2005	300
25	Bobs Creek	9/19/2005	300
25	Bobs Creek	9/21/2005	130
25	Bobs Creek	9/28/2005	70
26	Goose Creek	9/6/2005	300
26	Goose Creek	9/14/2005	240
26	Goose Creek	9/19/2005	130
26	Goose Creek	9/21/2005	80
26	Goose Creek	9/28/2005	220
29	North Muddy Creek	9/6/2005	110
29	North Muddy Creek	9/14/2005	300
29	North Muddy Creek	9/19/2005	220
29	North Muddy Creek	9/21/2005	240
29	North Muddy Creek	9/28/2005	500

B.3.2. 2006

Site ID	Stream Name	Date	Fecal Coliform (col/100/ml)
6	South Muddy Creek	8/2/2006	300
6	South Muddy Creek	8/8/2006	≥1600
6	South Muddy Creek	8/14/2006	900
6	South Muddy Creek	8/21/2006	300
6	South Muddy Creek	8/28/2006	280
9	Hoppers Creek	8/2/2006	220
9	Hoppers Creek	8/8/2006	1600
9	Hoppers Creek	8/14/2006	500
9	Hoppers Creek	8/14/2006	900
9	Hoppers Creek	8/21/2006	300
9	Hoppers Creek	8/21/2006	300
9	Hoppers Creek	8/28/2006	240
12	South Muddy Creek	8/2/2006	170
12	South Muddy Creek	8/8/2006	900
12	South Muddy Creek	8/14/2006	1600
12	South Muddy Creek	8/21/2006	300
12	South Muddy Creek	8/28/2006	240
12	South Muddy Creek	8/28/2006	240
16	North Muddy Creek	8/2/2006	300
16	North Muddy Creek	8/8/2006	240
16	North Muddy Creek	8/8/2006	170
16	North Muddy Creek	8/14/2006	900
16	North Muddy Creek	8/21/2006	500
16	North Muddy Creek	8/28/2006	170
22	Youngs Fork	8/2/2006	500
22	Youngs Fork	8/8/2006	900
22	Youngs Fork	8/14/2006	500
22	Youngs Fork	8/21/2006	900
22	Youngs Fork	8/28/2006	240
23	Jacktown Creek	8/2/2006	1600
23	Jacktown Creek	8/8/2006	300
23	Jacktown Creek	8/14/2006	900
23	Jacktown Creek	8/21/2006	500
23	Jacktown Creek	8/28/2006	900
25	Bobs Creek	8/2/2006	500
25	Bobs Creek	8/8/2006	≥1600
25	Bobs Creek	8/14/2006	300
25	Bobs Creek	8/21/2006	500
25	Bobs Creek	8/28/2006	300
26	Goose Creek	8/2/2006	500
26	Goose Creek	8/8/2006	130
26	Goose Creek	8/14/2006	300
26	Goose Creek	8/21/2006	240
26	Goose Creek	8/28/2006	110
29	North Muddy Creek	8/2/2006	1600
29	North Muddy Creek	8/8/2006	900
29	North Muddy Creek	8/14/2006	300
29	North Muddy Creek	8/21/2006	500
29	North Muddy Creek	8/28/2006	220

B.3.3. 2007

Site ID	Stream Name	Date	Fecal Coliform (col/100/ml)
6	South Muddy Creek	9/6/2007	580
6	South Muddy Creek	9/13/2007	450
6	South Muddy Creek	9/20/2007	330
6	South Muddy Creek	9/27/2007	1100
6	South Muddy Creek	10/4/2007	2900
9	Hoppers Creek	9/6/2007	300
9	Hoppers Creek	9/13/2007	248
9	Hoppers Creek	9/20/2007	>2600
9	Hoppers Creek	9/27/2007	300
9	Hoppers Creek	10/4/2007	570
12	South Muddy Creek	9/6/2007	>2600
12	South Muddy Creek	9/13/2007	280
12	South Muddy Creek	9/20/2007	224
12	South Muddy Creek	9/27/2007	330
12	South Muddy Creek	10/4/2007	1000
16	North Muddy Creek	9/6/2007	220
16	North Muddy Creek	9/13/2007	380
16	North Muddy Creek	9/20/2007	320
16	North Muddy Creek	9/27/2007	285
16	North Muddy Creek	10/4/2007	1980
22	Youngs Fork	9/6/2007	320
22	Youngs Fork	9/13/2007	1133
22	Youngs Fork	9/20/2007	410
22	Youngs Fork	9/27/2007	120
22	Youngs Fork	10/4/2007	>7467
25	Bobs Creek	9/6/2007	330
25	Bobs Creek	9/13/2007	375
25	Bobs Creek	9/20/2007	350
25	Bobs Creek	9/27/2007	260
25	Bobs Creek	10/4/2007	1500
26	Goose Creek	9/6/2007	350
26	Goose Creek	9/13/2007	360
26	Goose Creek	9/20/2007	221
26	Goose Creek	9/27/2007	212
26	Goose Creek	10/4/2007	390
29	North Muddy Creek	9/6/2007	222
29	North Muddy Creek	9/13/2007	410
29	North Muddy Creek	9/20/2007	390
29	North Muddy Creek	9/27/2007	285
29	North Muddy Creek	10/4/2007	1033

Appendix C

Field Forms

Appendix C

Table of Contents

Reach Log
NCDWQ Habitat Assessment Field Data Sheet
BEHI Form
Pebble Count and Embeddedness Forms
Virginia Save Our Streams Field Form

Reach Log

Stream: _____ Date: _____ Staff: _____

Reach Location: _____ Reach ID: _____ Drainage area: _____

A. Reach Delineation																												
<i>Downstream end of reach:</i> Location description _____ WP # _____ lat _____ long _____																												
<i>Upstream end of reach:</i> Location description _____ WP # _____ lat _____ long _____																												
<i>Reach direction:</i> station zero (tape) is <input type="checkbox"/> downstream end of reach <input type="checkbox"/> upstream end of reach																												
B. Transect Identification and Form Checklist																												
<i>Site 1:</i> Type: <input type="checkbox"/> riffle <input type="checkbox"/> pool <input type="checkbox"/> run Location (station or WP#) _____ Forms completed: BEHI _____, Pebble Count _____, Embeddedness _____, VASOS _____, XS _____ Notes _____																												
<i>Site 2:</i> Type: <input type="checkbox"/> riffle <input type="checkbox"/> pool <input type="checkbox"/> run Location (station or WP#) _____ Forms completed: BEHI _____, Pebble Count _____, Embeddedness _____, VASOS _____, XS _____ Notes _____																												
<i>Site 3:</i> Type: <input type="checkbox"/> riffle <input type="checkbox"/> pool <input type="checkbox"/> run Location (station or WP#) _____ Forms completed: BEHI _____, Pebble Count _____, Embeddedness _____, VASOS _____, XS _____ Notes _____																												
<i>Site 4:</i> Type: <input type="checkbox"/> riffle <input type="checkbox"/> pool <input type="checkbox"/> run Location (station or WP#) _____ Forms completed: BEHI _____, Pebble Count _____, Embeddedness _____, VASOS _____, XS _____ Notes _____																												
<i>Reach scale:</i> Habitat assessment completed for reach? _____																												
C. Water Quality and Flow Conditions																												
<i>Water Quality:</i> Temperature _____ °C DO _____ mg/L Specific conductance _____ µmhos/cm Location (if other than ds end of reach) _____	<i>Flow Conditions:</i> <input type="checkbox"/> high <input type="checkbox"/> normal <input type="checkbox"/> low Date of last rain: _____																											
D. Invasive Species in Riparian Zone																												
<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 30%;"></th> <th style="width: 10%; text-align: center;"><i>Present</i></th> <th style="width: 10%; text-align: center;"><i>Dominant</i></th> </tr> </thead> <tbody> <tr> <td>multiflora rose</td> <td style="text-align: center;"><input type="checkbox"/></td> <td style="text-align: center;"><input type="checkbox"/></td> </tr> <tr> <td>privet</td> <td style="text-align: center;"><input type="checkbox"/></td> <td style="text-align: center;"><input type="checkbox"/></td> </tr> <tr> <td>stilt grass</td> <td style="text-align: center;"><input type="checkbox"/></td> <td style="text-align: center;"><input type="checkbox"/></td> </tr> <tr> <td>knotweed</td> <td style="text-align: center;"><input type="checkbox"/></td> <td style="text-align: center;"><input type="checkbox"/></td> </tr> </tbody> </table>		<i>Present</i>	<i>Dominant</i>	multiflora rose	<input type="checkbox"/>	<input type="checkbox"/>	privet	<input type="checkbox"/>	<input type="checkbox"/>	stilt grass	<input type="checkbox"/>	<input type="checkbox"/>	knotweed	<input type="checkbox"/>	<input type="checkbox"/>	<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 30%;"></th> <th style="width: 10%; text-align: center;"><i>Present</i></th> <th style="width: 10%; text-align: center;"><i>Dominant</i></th> </tr> </thead> <tbody> <tr> <td>kudzu</td> <td style="text-align: center;"><input type="checkbox"/></td> <td style="text-align: center;"><input type="checkbox"/></td> </tr> <tr> <td>honeysuckle</td> <td style="text-align: center;"><input type="checkbox"/></td> <td style="text-align: center;"><input type="checkbox"/></td> </tr> <tr> <td>other (list below)</td> <td style="text-align: center;"><input type="checkbox"/></td> <td style="text-align: center;"><input type="checkbox"/></td> </tr> </tbody> </table>		<i>Present</i>	<i>Dominant</i>	kudzu	<input type="checkbox"/>	<input type="checkbox"/>	honeysuckle	<input type="checkbox"/>	<input type="checkbox"/>	other (list below)	<input type="checkbox"/>	<input type="checkbox"/>
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other (list below)	<input type="checkbox"/>	<input type="checkbox"/>																										
Other Reach Information																												
<i>Photos (list photo no. and location)</i> _____ _____ _____																												
<i>Bankfull indicators, height above water surface:</i> _____ _____ _____																												
Notes																												

Instructions for NCDWQ Habitat Assessment Field Data Sheet—Mountain/ Piedmont Streams

1. Select the reach to be assessed based on study objectives and site selection procedures.
2. A reach of at least 100 yards in length should be assessed.
3. The assessment should be conducted by a team by two or more observers.
4. The Field Data Sheet should be completed only after walking and observing the entire reach.
5. The assessment should reflect average or most typical reach conditions.
6. Complete the reach identification information.
7. Complete the assessment of the eight component metrics. For each metric, select the description which best fits the observed habitats and circle the score.
8. If the observed habitat falls between two descriptions, select an intermediate score.
9. The final score is determined by adding the scores of the component metrics.

Stream: _____ **Date:** _____ **Staff:** _____

Reach Location: _____ **Reach ID:** _____ **Drainage area:** _____

Notes: _____

NCDWQ Habitat Assessment Field Data Sheet—Mountain/ Piedmont Streams
from BAU 3/01 Revision 6

I. Channel Modification

	<u>Score</u>
A. channel natural, frequent bends.....	5
B. channel natural, infrequent bends (channelization could be old).....	4
C. some channelization present (recent).....	3
D. more extensive channelization (recent), >40% of stream disrupted.....	2
E. no bends, completely channelized or rip rapped or gabioned, etc.....	0
<input type="checkbox"/> Evidence of dredging <input type="checkbox"/> Evidence of desnagging=no large woody debris in stream <input type="checkbox"/> Banks of uniform shape/height	
Remarks _____	Subtotal _____

II. Instream Habitat: Consider the percentage of the reach that is favorable for benthos colonization or fish cover. If >70% of the reach is rocks, 1 type is present, circle the score of 17. Definition: leafpacks consist of older leaves that are packed together and have begun to decay (not piles of leaves in pool areas). Mark as Rare, Common, or Abundant.

Detail breakdown (WAT)

____ **Rocks** ____ **Macrophytes** ____ **Sticks and leafpacks** ____ **Snags and logs** ____ **Undercut banks or root mats**

AMOUNT OF REACH FAVORABLE FOR COLONIZATION OR COVER

	<u>>70%</u>	<u>40-70%</u>	<u>20-40%</u>	<u><20%</u>
	<u>Score</u>	<u>Score</u>	<u>Score</u>	<u>Score</u>
4 or 5 types present.....	20	16	12	8
3 types present.....	19	15	11	7
2 types present.....	18	14	10	6
1 type present.....	17	13	9	5
No types present.....	0			

No woody vegetation in riparian zone Subtotal _____
Remarks (characterize channel roughness, edge habitat, etc.): _____

Page Total _____

III. Bottom Substrate (silt, sand, detritus, gravel, cobble, boulder) look at entire reach for substrate scoring, but only look at riffle for embeddedness.

A. substrate with good mix of gravel cobble and boulders	<u>Score</u>
1. embeddedness <20% (very little sand, usually only behind large boulders).....	15
2. embeddedness 20-40%	12
3. embeddedness 40-80%	8
4. embeddedness >80%	3
B. substrate gravel and cobble	
1. embeddedness <20%	14
2. embeddedness 20-40%	11
3. embeddedness 40-80%	6
4. embeddedness >80%	2
C. substrate mostly gravel	
1. embeddedness <50%	8
2. embeddedness >50%	4
D. substrate homogeneous	
1. substrate nearly all bedrock.....	3
2. substrate nearly all sand	3
3. substrate nearly all detritus.....	2
4. substrate nearly all silt/ clay.....	1
	Subtotal _____

Remarks _____

IV. Pool Variety Pools are areas of deeper than average maximum depths with little or no surface turbulence. Water velocities associated with pools are always slow. Pools may take the form of "pocket water", small pools behind boulders or obstructions, in large high gradient streams.

A. Pools present	<u>Score</u>
1. Pools Frequent (>30% of 100m area surveyed)	
a. variety of pool sizes.....	10
b. pools same size (indicates pools filling in).....	8
2. Pools Infrequent (<30% of the 100m area surveyed)	
a. variety of pool sizes.....	6
b. pools same size.....	4
B. Pools absent	0
	Subtotal _____

Remarks _____

Pool bottom boulder-cobble=hard Bottom sandy-sink as you walk Silt bottom Some pools over wader depth

V. Riffle Habitats

Definition: Riffle is area of reaeration-can be debris dam, or narrow channel area.

	<u>Score</u>	<u>Score</u>
	Riffles Frequent	Riffles Infrequent
A. well defined riffle and run, riffle as wide as stream and extends 2X width of stream...	16	12
B. riffle as wide as stream but riffle length is not 2X stream width	14	7
C. riffle not as wide as stream and riffle length is not 2X stream width	10	3
D. riffles absent	0	
** riffle not as wide as stream but riffle length is 2X width of stream...score within range	10-14	3-7

Subtotal _____

Remarks _____

Page Total _____

VI. Bank Stability and Vegetation

FACE DOWNSTREAM

	Left Bank Score	Rt. Bank Score
A. Banks stable		
1. no evidence of erosion or bank failure(except outside of bends), little potential for erosion....	7	7
B. Erosion areas present		
1. diverse trees , shrubs, grass; plants healthy with good root systems.....	6	6
2. few trees or small trees and shrubs ; vegetation appears generally healthy.....	5	5
3. sparse mixed vegetation; plant types and conditions suggest poorer soil binding.....	3	3
4. mostly grasses , few if any trees and shrubs, high erosion and failure potential at high flow..	2	2
5. no bank vegetation, mass erosion and bank failure evident.....	0	0
	Subtotal _____	

Remarks _____

VII. Light Penetration (Canopy is defined as tree or vegetative cover directly above the stream's surface. Canopy would block out sunlight when the sun is directly overhead).

	Score
A. Stream with good shading with some breaks for light penetration	10
B. Stream with full canopy - breaks for light penetration absent.....	8
C. Stream with partial shading - sunlight and shading are essentially equal.....	7
D. Stream with minimal shading - full sun in all but a few areas.....	2
E. No shading	0
	Subtotal _____

Remarks _____

VIII. Riparian Buffer Width

Notes: *Riparian buffer* for this form is area of natural (woody) vegetation adjacent to stream (can go beyond floodplain). A *break* in the riparian buffer is any place on the stream banks which allows sediment or pollutants to directly enter the stream, such as paths down to stream, storm drains, uprooted trees, otter slides, etc. *Riparian zone* is the area adjacent to and influenced by the stream (floodplain and terraces), and it is often larger than the *riparian buffer*.

Dominant vegetation in riparian zone: Trees Shrubs Grasses Weeds/old field Exotics (kudzu,etc)

	Lft. Bank Score	Rt. Bank Score
A. Riparian buffer intact (no breaks)		
1. width > 18 meters.....	5	5
2. width 12-18 meters.....	4	4
3. width 6-12 meters.....	3	3
4. width < 6 meters.....	2	2
B. Riparian buffer not intact (breaks)		
1. breaks rare		
a. width > 18 meters.....	4	4
b. width 12-18 meters.....	3	3
c. width 6-12 meters.....	2	2
d. width < 6 meters.....	1	1
2. breaks common		
a. width > 18 meters.....	3	3
b. width 12-18 meters.....	2	2
c. width 6-12 meters.....	1	1
d. width < 6 meters.....	0	0
	Subtotal _____	

Remarks: _____

Page Total _____

TOTAL SCORE _____

BEHI	Date	Stream	Reach ID				Staff				
Station and Bank (descending)		Measures (ft)	BEHI Parameters				Index totals and adjustments				NBS
		Bank ht/ bkf ht	Root depth/ bank ht	Root density (%)	Bank angle (degrees)	Surface protection	Index total	Adjust: bank materials	Adjust: stratifi- cation	Adjusted total	Near bank stress
Station location/description _____											
<input type="checkbox"/> left bank <input type="checkbox"/> right bank	bank ht: _____ bkf ht: _____ root dpt: _____	value: _____ index: _____	value: _____ index: _____	value: _____ index: _____	value: _____ index: _____	value: _____ index: _____					
<input type="checkbox"/> left bank <input type="checkbox"/> right bank	bank ht: _____ bkf ht: _____ root dpt: _____	value: _____ index: _____	value: _____ index: _____	value: _____ index: _____	value: _____ index: _____	value: _____ index: _____					
Station location/description _____											
<input type="checkbox"/> left bank <input type="checkbox"/> right bank	bank ht: _____ bkf ht: _____ root dpt: _____	value: _____ index: _____	value: _____ index: _____	value: _____ index: _____	value: _____ index: _____	value: _____ index: _____					
<input type="checkbox"/> left bank <input type="checkbox"/> right bank	bank ht: _____ bkf ht: _____ root dpt: _____	value: _____ index: _____	value: _____ index: _____	value: _____ index: _____	value: _____ index: _____	value: _____ index: _____					

Adjustments

Bank materials-- Bedrock: bank erosion potential always v. low
 Boulders: bank erosion potential low
 Cobble: decrease by one category unless mix of gravel/sand is >50%
 Gravel: adjust values by 5-10 pts depending on composition of sand
 Sand: adjust values up by 10 pts
 Silt/clay: no adjustment

Stratification-- Adjust upwards by 5-10 pts depending on position of unstable layers in relation to bkf stage

Near bank stress Method is qualitative (low, med, high) judgment
low=stream velocity vectors pointing away from bank
med=stream velocity vectors parallel to bank
high=stream velocity vector pointing at bank

Parameter	very low		low		moderate		high		very high		extreme	
	value	index	value	index	value	index	value	index	value	index	value	index
bank ht/bkf ht	1.0-1.1	1.0-1.9	1.1-1.19	2.0-3.9	1.2-1.5	4.0-5.9	1.6-2.0	6.0-7.9	2.1-2.8	8.0-9.0	>2.8	10
root depth/bank ht	1.0-0.9	1.0-1.9	0.89-0.50	2.0-3.9	0.49-0.30	4.0-5.9	0.29-0.15	6.0-7.9	0.14-0.05	8.0-9.0	<0.05	10
root density (%)	100-80	1.0-1.9	79-55	2.0-3.9	54-30	4.0-5.9	29-15	6.0-7.9	14-5	8.0-9.0	<5	10
bank angle (degrees)	0-20	1.0-1.9	21-60	2.0-3.9	61-80	4.0-5.9	81-90	6.0-7.9	91-119	8.0-9.0	>119	10
surface protection (%)	100-80	1.0-1.9	79-55	2.0-3.9	54-30	4.0-5.9	29-15	6.0-7.9	14-10	8.0-9.0	<10	10
TOTALS		5.0-9.5		10-19.5		20-29.5		30-39.5		40-45		46-50

Pebble Count and Embeddedness Forms

Pebble Count

Site:	Date:
Names:	Reach:

Particle	Size (mm)	Type	# of Particles	Total #	%	Cum. %
Silt/Clay	< .062	S/C				
Very Fine	.062 - .125	S				
Fine	.125 - .25	A				
Medium	.25 - .5	N				
Coarse	.5 - 1.0	D				
Very Coarse	1 - 2	S				
Very Fine	2 - 4					
Fine	4 - 6	G				
Fine	6 - 8	R				
Medium	8 - 12	A				
Medium	12 - 16	V				
Coarse	16 - 24	E				
Coarse	24 - 32	L				
Very Coarse	32 - 48	S				
Very Coarse	48 - 64					
Small	64 - 96	C				
Small	96 - 128	O				
Large	128 - 192	B				
Large	192 - 256	L				
Small	256 - 384	B				
Small	384 - 512	L				
Medium	512 - 1024	D				
Lrg/Vry Lg	1024 - 4096	R				
Bedrock		BDRK				
TOTALS:						

Embeddedness Tally Sheet*

1	2	3	4	5	Median
6	7	8	9	10	
100% embedded (check) <input type="checkbox"/>					
No riffle (check) <input type="checkbox"/>					

*Record embeddedness for 10 particles in cells 1-10. Calculate median.

Virginia

Save Our Streams

Stream Quality Survey

For Office Use Only

Name of Reviewer _____

Date Reviewed _____

Date sent to _____

VA SOS Data Entry Date _____

The purpose of this form is to aid you in gathering and recording important data about the health of your stream. By keeping accurate and consistent records of your observations and data from your macroinvertebrate count, you can document changes in ecological condition. Refer to the *Virginia Citizen Monitor's Methods Manual* for instructions on how to collect and identify stream macroinvertebrates. *Please note, this method was designed and tested for conditions in the state of Virginia and may not be appropriate in other areas.*

Date _____

Stream _____ Station _____ # of participants _____

Group or individual _____

Name of **certified*** monitor _____

County _____ Latitude _____ Longitude _____

Location (please be specific) _____

Average stream width _____ ft Average stream depth _____ in

Flow rate: High _____ Normal _____ Low _____ Negligible _____

Weather last 72 hours _____

Water Temperature _____ °F (Please specify if reporting temperature in Celsius)

Collection Time:

Net 1: _____ sec


















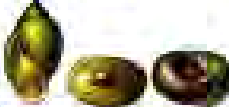


Net 2: _____ sec

Net 3: _____ sec

Net 4: _____ sec

Other comments:

Virginia Save Our Streams Macroinvertebrate Tally Sheet

Macroinvertebrates	Tally	Count	Macroinvertebrates	Tally	Count
Worms 			Common Nematodes 		
Flat Worms 			Most Caddisflies 		
Leeches 					
Crayfishes 			Beetles 		
Sowbugs 			Midges 		
Scuds 			Black Flies 		
Stoneflies 			Most True Flies 		
Mayflies 			Billed Snails 		
Dragonflies and Damselflies 			Lunged Snails 		
Helgrammites, Fishflies, and Alderflies 			Clams 		
			Other Subsurface organisms (please specify if possible - if you do not know if the organism is subsurface, please do not include in the total)		
			Total number of organisms in the sample		

Illustrations from: Voshell, J. R., Jr. 2001. *Guide to the Common Freshwater Invertebrates of North America*. MacDonald and Woodward Publishing Co. With permission of the author.

Individual Metrics

Metric Number	Metric Organism Group	Number of metric organism		Total number of organisms in the sample		Percent (This is your value for this metric)
1	Mayflies + Stoneflies + Most Caddisflies		÷		Multiply by 100	%
2	Common Netspinners		÷		Multiply by 100	%
3	Lunged Snails		÷		Multiply by 100	%
4	Beetles		÷		Multiply by 100	%

Metric 5 - % Tolerant

Taxon	Number
Worms	
Flatworms	
Leeches	
Soebugs	
Scuds	
Dragonflies and Damselflies	
Midges	
Black Flies	
Lunged Snails	
Clams	
Total Tolerant	
Total Tolerant divided by the total number of organisms in the sample	
Multiply by 100	
This is your Value for Metric 5	

Metric 6 - % Non-Insects

Taxon	Number
Worms	
Flatworms	
Leeches	
Crayfish	
Soebugs	
Scuds	
Gilled Snails	
Lunged Snails	
Clams	
Total Non-Insects	
Total Non-Insects divided by the total number of organisms in the sample	
Multiply by 100	
This is your Value for this Metric 6	

Save Our Streams Multimetric Index

Write your metric value from the previous page in the 2nd column (Your Metric Value). Determine whether each metric should get a score of 2, 1, or 0 - depending upon the range of your metric value. Put a check in the appropriate box for your metric value under 2, 1, or 0. Count the total number of 2's, 1's, and 0's. Follow the multiplication at the bottom of the chart to determine your Save Our Streams Multimetric Index score and determine whether the site has acceptable or unacceptable ecological condition.

Metric Number	Metric Organism	Your Metric Value	2	1	0
1	% Mayflies + Stoneflies + Most Caddisflies		Greater than 32.2	16.1 - 32.2	Less than 16.1
2	% Common Netspinners		Less than 19.7	19.7 - 34.5	Greater than 34.5
3	% Lunged Snails		Less than 0.3	0.3 - 1.5	Greater than 1.5
4	% Beetles		Greater than 6.4	3.2 - 6.4	Less than 3.2
5	% Tolerant		Less than 46.7	46.7 - 61.5	Greater than 61.5
6	% Non-Insects		Less than 5.4	5.4 - 20.8	Greater than 20.8
			Total # of 2s	Total # of 1s	Total # of 0s
			Multiply by 2:	Multiply by 1:	Multiply by 0:
Subtotals:					
<p>Now add the 3 subtotals to get the Save Our Streams Multimetric Index score: _____</p> <p>_____ Acceptable ecological condition (7 to 12) _____ Unacceptable ecological condition (0 to 6)</p>					

Please send data sheets to your regional coordinator or VA SOS, P.O. Box 8297, Richmond, Va 23226. If you have any questions about the modified method or this particular collection, please call 804-615-3036 or e-mail stacey@vasos.org

Appendix D
Ancillary Data

Appendix D

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Table D.1. Land Cover by Sub-watershed (Acres), 1998

Table D.2. Land Cover by Sub-watershed (Acres), 2005

Table D.3. Pre 2005 Benthic Community Data Collected by Duke Energy at Sites 6 and 16

Table D.4. Benthic Community Data for Sites Monitored by NCDWQ on North and South Muddy Creeks, 2002- 2007

Table D.5. Fish Community Data for Sites Monitored by NCDWQ on North and South Muddy Creeks, 2002- 2007

Figure D.1.

Monthly Precipitation in Marion, 2005-2007, and Long Term Average (Station 315240)

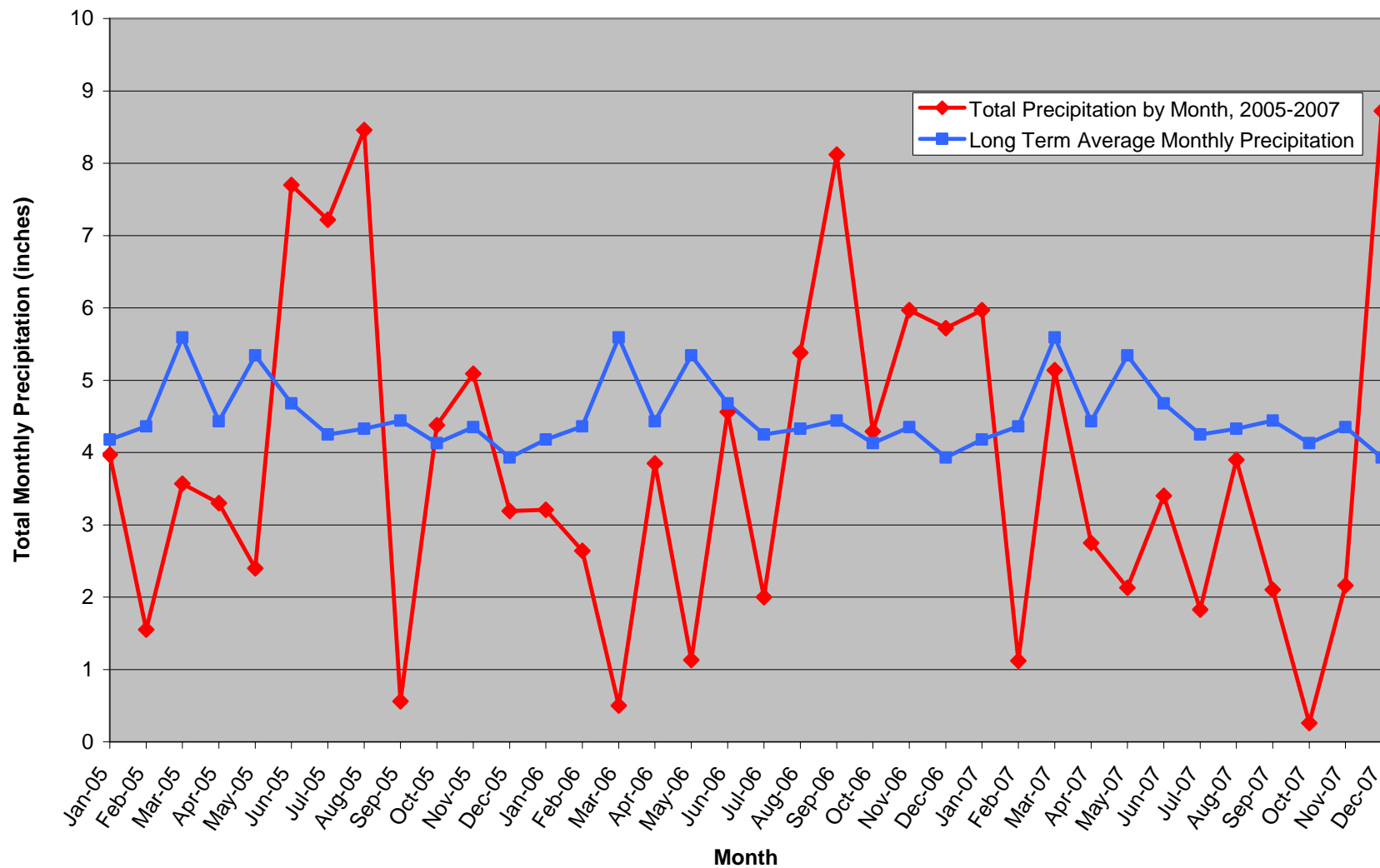


Figure D.2. South Muddy Creek (Site 6): Maximum Daily Stage, May 2006 - December 2007

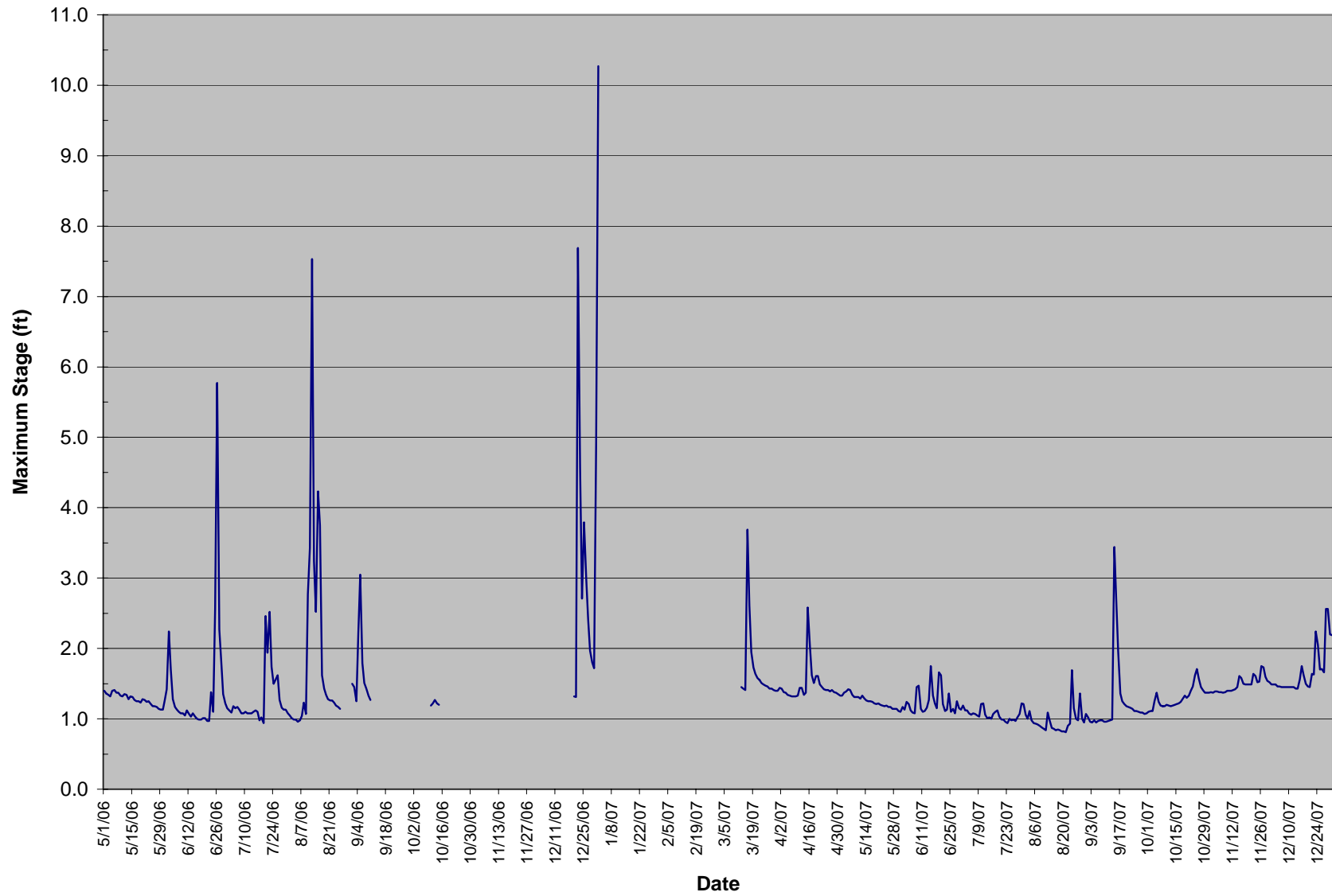


Figure D.3. Bobs Creek (Site 25): Maximum Daily Stage, May 2006 - December 2007

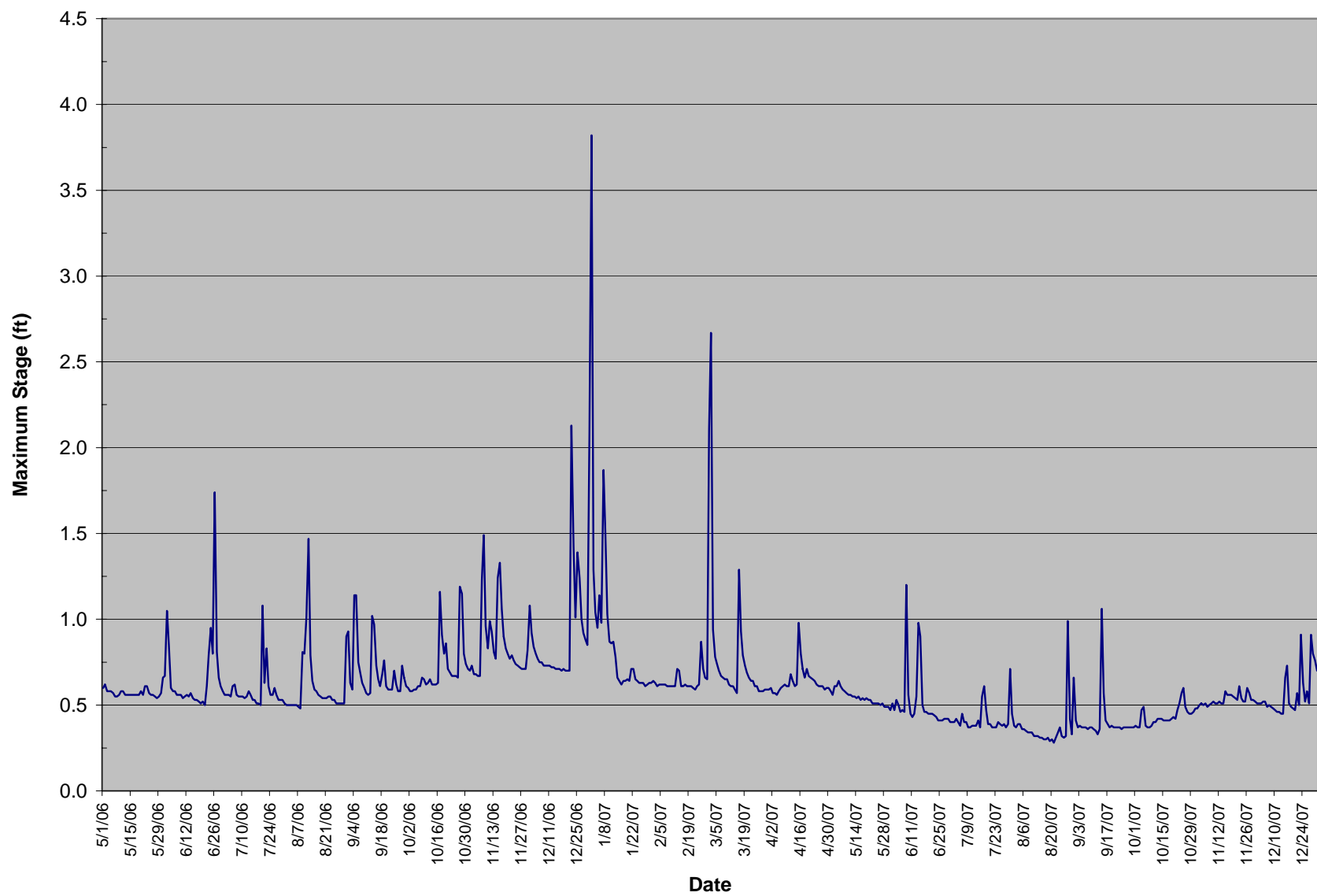


Table D.1. Land Cover by Sub-watershed (acres), 1998

Land Cover Classification	North Muddy Ck Drainage							South Muddy Ck Drainage					Lower Muddy Ck	
	NM-HW	GC	NM-U/BC	YF	NM-M	NM-L	TF	SM-HW	SM-U	SM-M	HC	SM-L	LM	OC/SD
Forested	4,539.2	4,620.4	2,583.9	3,290.4	4,536.9	2,831.5	3,709.2	4,240.7	3,533.7	4,562.4	5,442.7	2,830.6	3,547.3	3,555.4
Mixed Forest	3,900.1	3,460.8	1,891.5	2,738.5	3,335.5	2,230.8	3,256.5	2,541.0	2,349.2	2,854.5	3,476.7	1,912.9	1,612.3	2,084.3
Harvested 5-10	133.9	194.1	107.3	90.3	112.3	0.0	81.0	0.5	373.2	179.5	50.8	279.8	345.0	103.5
Harvested 0-5	226.2	649.0	238.5	216.5	347.0	189.9	124.4	614.0	460.7	325.8	460.9	309.9	890.3	104.5
Plantation	63.0	187.0	283.8	32.9	592.7	322.1	142.2	1,039.7	339.7	991.3	1,329.9	262.6	609.6	1126.7
Shrub/Scrub	215.9	129.4	63.0	212.3	149.4	88.6	105.0	45.4	11.0	211.2	124.3	65.4	90.1	136.4
Agricultural	791.9	970.6	565.1	287.6	557.3	514.4	409.5	126.6	142.7	997.6	1,275.1	797.5	507.3	665.7
Pasture	562.5	763.6	396.6	262.2	544.7	453.3	338.2	118.2	124.8	741.1	832.0	577.8	305.6	492.4
Cropland	223.1	207.0	107.1	25.4	12.7	56.2	59.6	8.4	5.4	122.6	298.5	204.4	181.0	48.4
Nursery	6.3	0.0	61.3	0.0	0.0	0.0	1.4	0.0	3.5	118.7	126.1	0.0	20.8	124.9
Poultry Operation	0.0	0.0	0.0	0.0	0.0	4.9	10.3	0.0	9.1	15.2	18.4	15.3	0.0	0.0
Urban/Built Up	1,420.8	341.7	150.6	1,578.0	694.4	392.7	725.0	113.0	85.3	465.6	231.2	369.2	571.9	479.0
Residential	1,072.0	311.4	101.5	941.7	635.6	298.9	653.9	107.7	83.4	443.1	212.1	306.7	506.0	409.5
Commercial	211.0	8.6	0.0	445.8	10.5	58.8	33.4	5.4	0.0	13.5	8.0	36.0	22.7	44.9
Transportation	121.9	16.1	12.7	101.0	47.9	31.9	27.2	0.0	1.9	9.0	11.1	26.6	33.2	24.5
Mixed Urban	15.8	0.0	36.4	83.8	0.4	3.1	10.5	0.0	0.0	0.0	0.0	0.0	10.0	0.0
Recreation	0.0	5.5	0.0	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	91.9	48.9	38.9	208.3	74.9	10.5	37.7	3.3	33.0	33.8	117.9	5.0	41.3	10.6
Altered Lands	66.1	21.6	37.2	197.0	65.8	5.7	21.3	2.7	19.6	14.3	12.5	3.3	36.7	9.3
Water	25.8	27.3	1.7	11.3	9.1	4.9	16.4	0.6	13.4	19.4	105.4	1.7	4.6	1.3
Total Area Acres	6,844	5,982	3,338	5,364	5,863	3,749	4,881	4,484	3,795	6,059	7,067	4,002	4,668	4,711
Sq. Miles	10.7	9.3	5.2	8.4	9.2	5.9	7.6	7.0	5.9	9.5	11.0	6.3	7.3	7.4

Table D.2. Land Cover by Sub-watershed (acres), 2005

Land Cover Classification	North Muddy Ck Drainage							South Muddy Ck Drainage					Lower Muddy Ck	
	NM-HW	GC	NM-U/BC	YF	NM-M	NM-L	TF	SM-HW	SM-U	SM-M	HC	SM-L	LM	OC/SD
Forested	4,537.8	4,601.1	2,490.7	3,437.3	4,377.8	2,759.8	3,687.9	4,237.6	3,462.5	4,517.9	5,278.0	2,764.1	3,439.4	3,513.2
Mixed Forest	3,287.4	2,883.0	2,027.0	2,583.5	3,076.6	2,092.7	3,071.6	2,062.5	1,822.2	2,746.6	3,075.3	1,692.5	1,566.7	2,372.3
Harvested 5-10	391.9	992.4	274.3	311.5	723.1	344.7	213.8	572.3	1,024.3	575.1	522.1	653.6	1,239.7	154.2
Harvested 0-5	549.0	307.7	25.3	148.1	137.5	23.1	137.5	876.5	360.2	377.6	934.1	150.3	154.8	260.0
Plantation	54.1	245.3	61.6	33.7	209.6	172.7	85.4	696.1	202.0	569.4	579.9	133.6	358.7	560.1
Shrub/Scrub	255.4	172.6	102.5	360.6	231.0	116.6	179.6	30.2	53.8	249.1	166.6	134.1	119.6	166.5
Agricultural	692.9	864.5	504.0	260.7	498.0	425.2	326.2	102.5	129.9	889.1	1,180.6	768.3	539.9	642.9
Pasture	571.6	698.9	334.7	223.6	477.5	334.6	257.4	93.9	112.7	659.6	917.7	419.9	301.8	409.9
Cropland	96.9	94.9	57.0	37.0	12.7	69.5	58.6	8.6	8.2	138.6	187.3	274.9	135.2	27.4
Nursery	24.4	70.7	112.3	0.2	7.8	14.3	0.0	0.0	0.0	77.7	57.3	61.1	102.9	205.6
Poultry Operation	0.0	0.0	0.0	0.0	0.0	6.8	10.3	0.0	9.1	13.2	18.3	12.3	0.0	0.0
Urban/Built Up	1,584.2	464.9	210.9	1,649.6	954.1	554.9	830.2	143.6	185.5	614.4	460.9	457.2	635.6	548.0
Residential	1,190.3	421.1	161.5	972.6	873.6	456.2	750.4	140.8	180.8	586.7	438.7	383.1	538.4	458.0
Commercial	244.1	19.3	0.4	432.5	30.1	63.7	40.1	2.2	2.8	18.8	10.7	47.6	56.2	60.0
Transportation	131.3	16.1	12.7	121.3	48.1	31.9	27.2	0.0	1.9	9.0	11.1	26.6	33.2	24.5
Mixed Urban	15.7	0.0	36.4	117.5	2.2	3.2	12.5	0.6	0.0	0.0	0.4	0.0	7.9	2.2
Recreation	2.9	8.3	0.0	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3
Other	28.9	50.9	132.8	15.4	33.3	19.2	36.9	0.0	16.9	37.9	147.3	12.7	52.8	6.6
Altered Lands	4.2	23.6	125.9	4.1	20.2	14.3	14.4	0.0	0.0	16.9	34.7	8.3	46.2	5.4
Water	24.7	27.3	7.0	11.3	13.2	4.9	22.6	0.0	16.9	20.9	112.7	4.4	6.6	1.3
Total Area Acres	6,844	5,982	3,338	5,364	5,863	3,749	4,881	4,484	3,795	6,059	7,067	4,002	4,668	4,711
Sq. Miles	10.7	9.3	5.2	8.4	9.2	5.9	7.6	7.0	5.9	9.5	11.0	6.3	7.3	7.4

Table D.3. Pre 2005 Benthic Community Data Collected by Duke Energy at Sites 6 and 16¹

Site and Indicator	Year					
	1999	2000	2001	2002	2003	2004
Site 6 South Muddy Creek						
Total EPT Taxa	21	21	10	12	11	16
Biotic Index	5.49	5.57	5.06	6.27	5.22	5.24
Bioclassification ²	GF	GF	F	F	F	F
Site 16 North Muddy Creek						
Total EPT Taxa	19	20	8	8	11	15
Biotic Index	5.57	5.33	5.79	6.15	5.26	5.45
Bioclassification ²	F	GF	F	P	F	F

(1) Source: Duke Energy, 2008. *Muddy Creek Macroinvertebrate Bioassessment Project, 2007*. March.

Data were collected for earlier monitoring efforts and not as part of the current monitoring project.

(2) Bioclassification key: P=Poor, F=Fair, GF=Good-Fair, G=Good, E=Excellent. Classifications of Poor and Fair indicate impairment.

Table D.4. Benthic Community Data for Sites Monitored by NCDWQ on North and South Muddy Creeks, 2002- 2007

Site & Indicator	August 2002	July 2007
South Muddy Ck at SR 1764		
Total EPT Taxa	23	32
EPT Biotic Index	4.22	3.94
Bioclassification	Good-Fair	Good
North Muddy Ck at SR 1760		
Total EPT Taxa	32	25
Biotic Index	5.51	5.36
Bioclassification	Good-Fair	Good-Fair

Table D.5. Fish Community Data for Sites Monitored by NCDWQ on North and South Muddy Creeks, 2002- 2007

Site & Indicator	April-May 2002	May 2007
South Muddy Ck at SR 1764		
Total Species	14	16
NCIBI	48	52
Bioclassification	Good	Good
North Muddy Ck at SR 1760		
Total Species	19	23
NCIBI	48	54
Bioclassification	Good	Excellent

Appendix E

Analyzing Restoration Effects – A Review of Key Issues

Analyzing Restoration Effects – A Review of Key Issues

As noted in Section 5, identifying potential beneficial effects of stream improvement projects requires that:

- An improvement in environmental conditions has actually occurred;
- The improvement is measurable and distinguishable from normal variation in conditions; and
- It is reasonable to attribute the observed change to the intervention as opposed to other events or circumstances.

A comprehensive review of all of the issues involved is beyond the scope of this report. This Appendix provides a brief review of some of the key factors as they pertain to the Muddy Creek watershed.

E.1 Have Stream Conditions Improved?

Restoration efforts are unlikely to result in improved environmental conditions unless:

1. Project design is sound and projects are implemented properly;
2. At the sub-watershed and watershed scales, the extent of stream improvement activity is adequate to address the problem;
3. Improvements due to restoration are not obscured by the negative impacts of other activities; and
4. Sufficient time has elapsed for measurable changes to manifest themselves.

Sound design and implementation at the site scale. Inadequacies in design and construction can clearly affect the results of a stream project. For example, a channel restoration project is unlikely to produce a stable channel if the new channel is not sized properly or channel structures are not properly installed. A revegetation project may not result in the anticipated improvements in riparian function if specifications call for species that will not do well under conditions at the site, if poor quality stock are used, or if planting densities are inadequate.

Extent of stream improvement activity. With proper assessment, design and implementation, a particular project will likely be adequate to address on-site problems. However, when broader scale improvements are the focus, the situation is more complex. It is necessary to consider whether the projects implemented have addressed a sufficient portion of the problems in a drainage to improve conditions downstream, in reaches which have not themselves been a focus of restoration activity.

As discussed in Section 4, over 50,000 feet of stream improvement has been completed in the Muddy Creek watershed. While this is a substantial amount of work, it represents less than 3% of the total stream network and only about 9% of the stream length identified in the 2003 restoration plan as priority areas for restoration activities.

In considering whether this effort is sufficient for broad scale conditions to be reasonably expected, it is instructive to review some basic features of sediment transport. Excess sediment

deposition at the watershed scale has occurred because sediment supply, from all sources, exceeds the capacity of the stream to transport it. Overall sedimentation will decrease when sediment supply is reduced below transport capacity and the stream can begin removing deposited materials.

Since neither transport capacity nor sediment loads have been quantified, there is no way to estimate whether any load reductions from stream projects completed to date might be sufficient to improve downstream channel conditions. It is clear, however, that a large majority of the stream and riparian deficiencies previously identified have yet to be addressed. From the perspective of projects completed, the sub-watershed for which impacts are most likely to be detectable may be Goose Creek, where completed restoration projects account for almost 10% of the total stream length and 24% of the priority stream length (see Table 4.3). A flood control facility is located on Goose Creek, but all completed projects are downstream of this impoundment.

It is also critical to realize that stream bank erosion, the primary sediment source addressed by stream improvement efforts being implemented in the Muddy Creek watershed, is not the only source of sediment in the watershed. The magnitude of sediment inputs from upland sources has not been quantified. If these sources are significant and sediment loading remains above stream transport capacity after stream bank sources have been substantially reduced, impacts from excessive deposition may remain.

Offsetting impacts. If sediment inputs from upland activities have actually increased during the monitoring period this could offset load reductions stemming from stream improvement projects. No data on this issue are available. While it appears that construction activity in McDowell County, as measured by building permits, has been increasing (see Section 2), it is not clear whether this trend is applicable to the Muddy Creek watershed or what the implications for sediment loading might be.

Elapsed time. As discussed in Section 4, some conditions at restored sites may (depending upon the nature of the restoration project) be expected to improve immediately upon project completion, while other conditions could take years to improve. Where monitoring occurs soon after a project has been completed, some site improvements will not have had time to develop. The issue is even more salient at the sub-watershed scale because of the time lag required for sediment transport, especially for bedload. Once sediment inputs are reduced at project locations, sediment impacts at downstream locations will not be reduced until some portion of the sediment already in the channel network has been flushed from the system. This process could take years, depending upon how far downstream the monitoring site is from the restoration project, the balance between transport capacity and supply, the sequence of storm events necessary to move the sediment, and other variables.

Given the recent nature of much of the restoration in Muddy Creek and the relatively low stream flows during 2007, it may be premature to expect that substantial reduction in downstream sediment deposition has yet occurred at broader scales. Seventy-five percent of the total linear extent of projects implemented was completed during the past three years, with the remaining twenty-five percent of the work completed during the second half of 2007. In the Goose Creek

sub-watershed, where restoration has been most extensive relative to the size of the channel system and documented needs, more than half of the project length was completed immediately prior to the 2007 monitoring.

E.2 Are Stream Improvements Identifiable?

Where improvements have actually occurred, they must be reliably identified and measured. This will not be possible unless:

1. Data are collected for the appropriate indicators; and
2. Improvements are large enough to be distinguishable from background variability, considering the precision with which indicators are measured.

Indicators. The primary indicators used in this study should be sensitive to the types of impacts expected at the site scale, although it may take some time for improved conditions to develop. However, not all of these indicators are likely to be useful at broader scales. In particular, bank erosion potential at broad-scale sites is primarily influenced by site specific factors such as the height and steepness of banks, as well as the nature of bank materials and extent of vegetation. Bank erosion at these locations is unlikely to be highly sensitive to the types of upstream site improvements implemented in the watershed. Many of the metrics that comprise the aquatic habitat score are also not likely to be affected. The parameters most likely to be impacted at scales broader than the site level are those sensitive to changes in sediment supply, in particular embeddedness and sediment size measures.

Background Variability. The indicators used must be measured at a level of precision that makes it possible to distinguish actual change from normal environmental variation. This issue is partly one of sample size and monitoring frequency. Three years of annual monitoring data do not provide sufficient information to identify the extent of variability nor, in many cases, to draw confident conclusions for parameters for which variability is expected to be large. As discussed in Appendix F, the quarterly data available for several sites in the Muddy Creek watershed indicate large fluctuations in values for substrate parameters such as embeddedness and median substrate size (D_{50}), while variability is much smaller for aquatic habitat and bank erosion potential. Fluctuations in VASOS scores lie somewhere in between. This variability can be viewed as the background noise from which any signal due to restoration projects or other management actions must be distinguished. The quarterly data strongly suggest that it will be more difficult to reliably establish trends in embeddedness and median substrate size than for the other primary indicators, especially where only three years of annual data are available.

E.3 Can Identified Improvements Be Attributed to Restoration?

Where the extent of actual improvements can be reliably determined, one must determine whether observed changes can be reasonably attributed to restoration activities, or whether they may be due to other factors. Two such factors that must be considered are:

1. Changing hydrologic or meteorological conditions; and

2. Changes in watershed management and pollution inputs other than those related to the projects being evaluated.

Changing hydrologic conditions. As documented in Section 2, precipitation and stream discharge declined during the monitoring period, especially during the third year (2007). By and large, the three sets of annual monitoring events thus reflect the influence of differing hydrologic conditions. Lower storm frequency and magnitude will in theory be reflected in lower sediment inputs as well as reduced sediment transport. However, these impacts cannot be precisely specified.

Complications due to other watershed activity. Stream conditions are influenced by a wide variety of watershed activities. This is a factor even at the scale of individual restoration sites, since most projects have at least a small upstream area providing drainage. The issue becomes more complex at broader scales. While some data on land cover change are available, data on the extent of upstream disturbance during the course of the project do not exist. No information on changes in watershed management practices (e.g. construction site erosion control or forestry management) was systematically collected, although anecdotal information and informal observations made by project staff are available.

Specific events can also complicate interpretation of data. For example, during maintenance activities at a dam on South Muddy Creek in the summer of 2006, large amounts of accumulated sediment were released into the stream above Site 13. This had a significant impact on substrate indicators at the site and necessitated moving transects within the reach. In 2006, beavers constructed a dam on Bobs Creek downstream of the study reach (Site 25) that inundated much of the reach for a time. The dam was removed by the landowner and rebuilt by the beavers on several occasions.

Appendix F

Analysis of Quarterly Stream Data

Analysis of Quarterly Stream Data

F.1 Introduction

Because three years of annual data provide limited information on inherent variability in stream conditions, quarterly monitoring of selected physical parameters was conducted at six sites (Table F.1). The six sites were selected to represent a range of conditions across the watershed. At these locations, supplemental quarterly monitoring was conducted in the three seasons not covered by the annual monitoring, for a total of four monitoring events per year. Funding limitations precluded collecting seasonal data at all locations.

The quarterly data collected at these sites is limited to the following subset of primary indicators: pebble counts; riffle embeddedness; Bank Erosion Hazard Index (BEHI); NCDWQ stream habitat protocol; benthic macroinvertebrate community condition (Virginia Save Our Streams protocol, or VASOS). Water quality field parameters (dissolved oxygen, specific conductance and temperature) were also monitored.

Including the annual monitoring, each site was monitored on nine occasions, once in 2005 (summer-fall) and four times each (winter, spring, summer, fall) in 2006 and 2007. At several sites VASOS and embeddedness were not monitored during every event because riffles were not present in the reach.

Table F.1. List of Sites in the Muddy Creek Watershed with Quarterly Data Collection

Station ID	Stream Name	Road Name	Drainage Area (sq mi)
06	South Muddy Ck.	Gilbert Byrd Road	39.7
13	South Muddy Ck.	Hwy NC 226	12.9
15	UT to S. Muddy Ck.	Brackett Town Road	0.5
16	North Muddy Ck.	Gilbert Byrd Road	56.3
19	North Muddy Ck.	Burma Road	42.8
25	Bobs Creek ²	Marlowe Road	2.1

F.2 Results

A summary of trends and patterns for selected parameters is presented below, including all monitoring events for each site. Plots and statistical summaries of key parameters are included at the end of this Appendix (Figures F.1-F.5 and Tables F.3-F.7).

Trends. Based on a visual inspection of plots (Figures F.1-F.2), obvious temporal trends are generally not apparent.

- Habitat - Habitat in Bobs Creek (Site 25) appears to be improving. Habitat at other sites is either declining or remains unchanged.

- BEHI - No trend is apparent at most sites, though the lower North Muddy Creek (Site 16) and Bobs Creek appeared to show modest improvement during the latter portion of the monitoring period.
- Trends in the remaining parameters examined are difficult to discern because variability in the measurements is much greater. The VASOS scores appear to have declined in Bobs Creek and increased in upper South Muddy Creek (Site 13).

Variability. The plotted data indicated considerable fluctuation from event to event for some parameters. This variability is reflected in the coefficient of variation (CV), which is defined as the standard deviation (measure of the average deviation from the mean) expressed as a percentage of the mean. Aquatic habitat and bank erosion potential CVs are relatively low (<10% on average), indicating that measurements at individual sites do not vary much over time (Table F.2). This is consistent with the plotted data. This is not a surprising finding, as there is no reason to expect significant seasonal variation in overall habitat conditions and bank stability, though seasonal differences in the appearance of vegetation can make some habitat and BEHI metrics more difficult to evaluate.

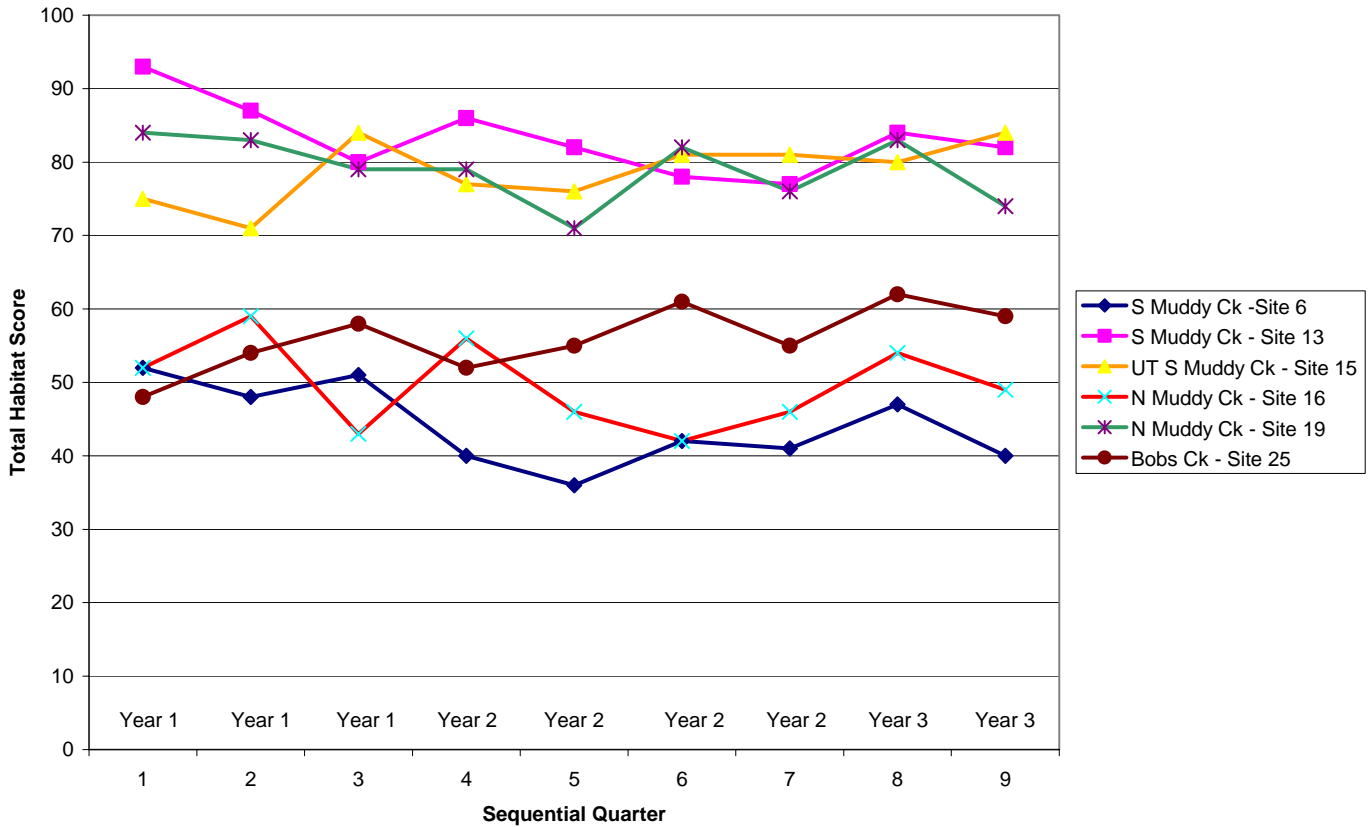
Variability in median riffle substrate size (D_{50}) and embeddedness are much higher (an average of 67% and 33%, respectively). This is rather consistent across sites. This also is not unexpected. Fluctuation in substrate parameters is likely due the episodic nature of bedload transport and variations in the magnitude and timing of flushing events. This is especially true in a dynamic system such as Muddy Creek.

Table F.2. Coefficients of Variation (CV) for Quarterly Monitoring Sites

Site ID	Indicator				
	Habitat	VASOS	Embeddedness	BEHI	D_{50} (Riffle)
6	13%	23%	26%	8%	104%
13	6%	18%	42%	7%	122%
15	6%	12%	34%	13%	46%
16	12%	25%	27%	5%	30%
19	6%	18%	41%	9%	59%
25	8%	27%	25%	12%	41%
Mean CV	8%	20%	33%	9%	67%

Figure F.1.

Aquatic Habitat Scores at Quarterly Monitoring Sites



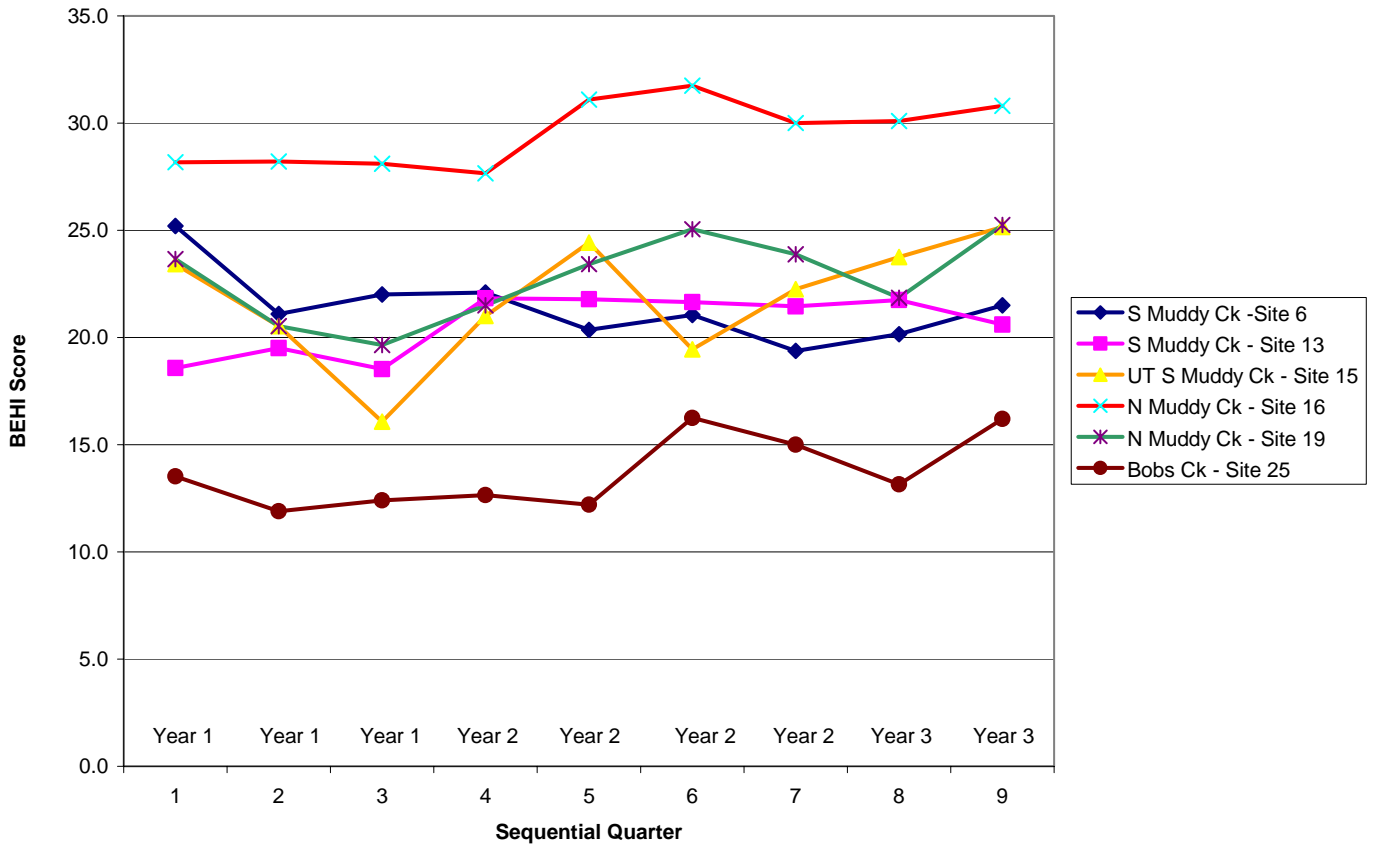
Note: Possible habitat scores range from 0 (worst habitat) to 100 (best habitat).

Table F.3. Summary of Seasonal Data - Aquatic Habitat Score

Indicator	Site					
	Site 6	Site 13	Site 15	Site 16	Site 19	Site 25
Mean	44.1	83.2	78.8	49.7	79.0	56.0
Median	42.0	82.0	80.0	49.0	79.0	55.0
Standard Deviation	5.6	5.0	4.4	5.9	4.5	4.5
Coefficient of Variation	13%	6%	6%	12%	6%	8%
Range	16	16	13	17	13	14
Minimum	36	77	71	42	71	48
Maximum	52	93	84	59	84	62
N	9	9	9	9	9	9

Figure F.2.

BEHI Scores at Quarterly Monitoring Sites



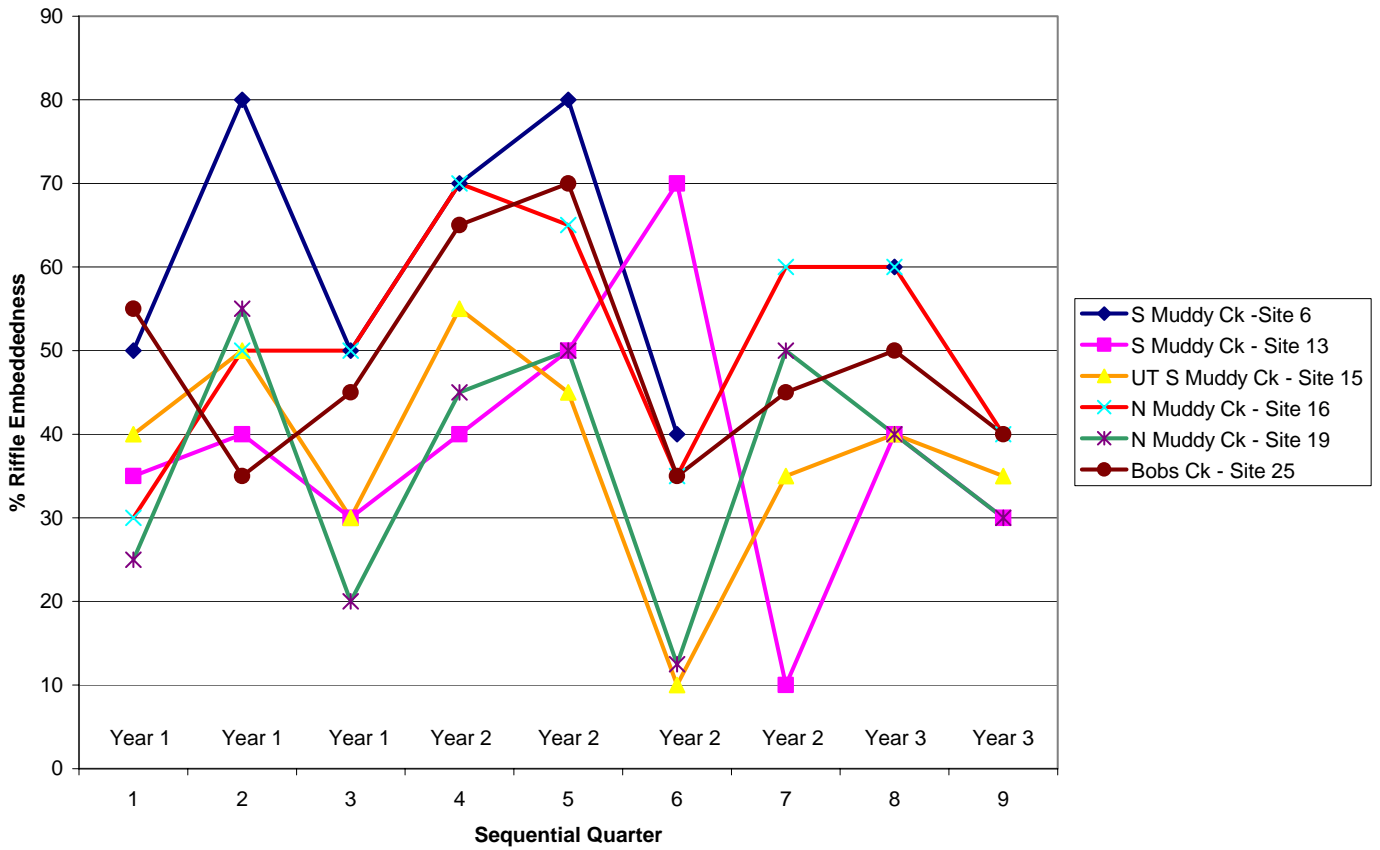
Note: Possible Bank Erosion Hazard Index (BEHI) scores range from 5 (extremely stable) to 50 (extremely unstable).

Table F.4. Summary of Seasonal Data - BEHI Score

Indicator	Site					
	Site 6	Site 13	Site 15	Site 16	Site 19	Site 25
Mean	21.4	20.6	21.8	29.5	22.8	13.7
Median	21.1	21.5	22.3	30.0	23.4	13.2
Standard Deviation	1.7	1.4	2.9	1.5	2.0	1.7
Coefficient of Variation	8%	7%	13%	5%	9%	12%
Range	6	3	9	4	6	4
Minimum	19	19	16	28	20	12
Maximum	25	22	25	32	25	16
N	9	9	9	9	9	9

Figure F.3.

Percent Riffle Embeddedness Scores at Quarterly Monitoring Sites



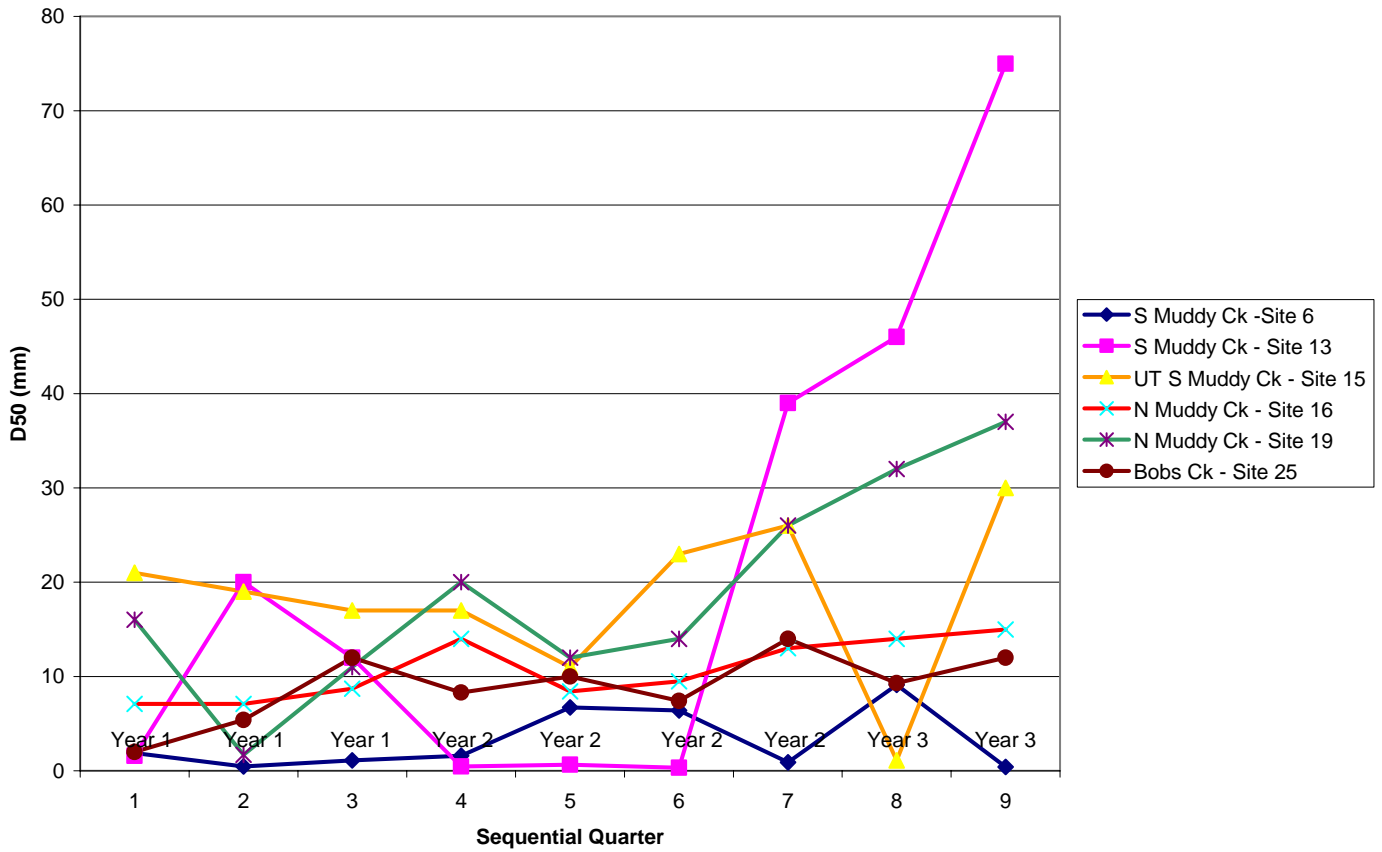
Note: Possible riffle embeddedness values range from 0% (not embedded) to 100% (completely embedded).

Table F.5. Summary of Seasonal Data - Embeddedness (%)

Indicator	Site					
	Site 6	Site 13	Site 15	Site 16	Site 19	Site 25
Mean	61.4	38.3	37.8	51.1	36.4	48.9
Median	60.0	40.0	40.0	50.0	40.0	45.0
Standard Deviation	15.7	16.2	13.0	13.9	15.1	12.4
Coefficient of Variation	26%	42%	34%	27%	41%	25%
Range	40	60	45	40	43	35
Minimum	40	10	10	30	13	35
Maximum	80	70	55	70	55	70
N	7	9	9	9	9	9

Figure F.4.

Riffle D50 at Quarterly Monitoring Sites



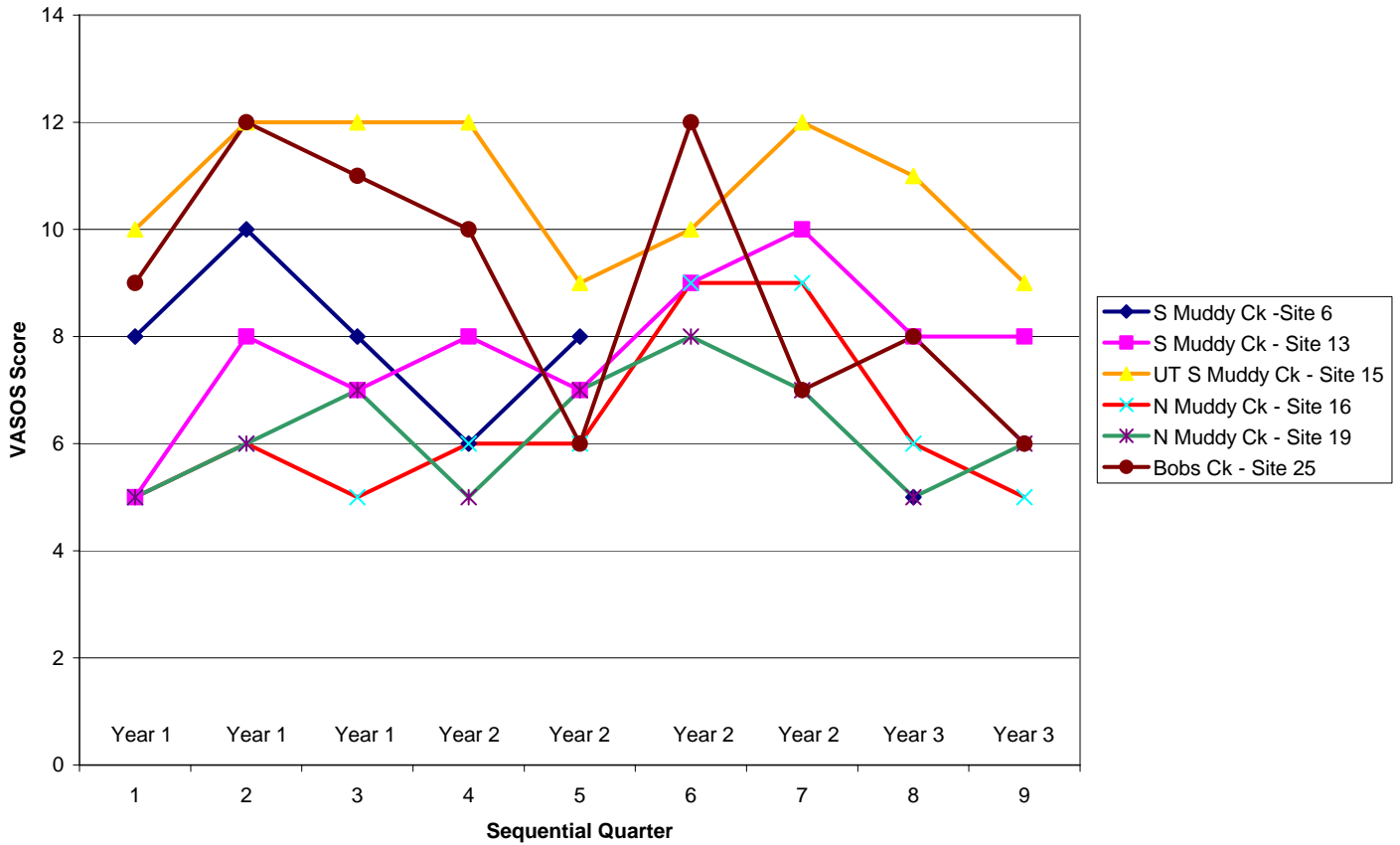
Note: D₅₀ values reflect median riffle particle size in mm.

Table F.6. Summary of Seasonal Data – Riffle D₅₀ (mm)

Indicator	Site					
	Site 6	Site 13	Site 15	Site 16	Site 19	Site 25
Mean	3.2	21.7	18.3	10.8	18.9	8.9
Median	1.6	12.0	19.0	9.5	16.0	9.3
Standard Deviation	3.3	26.4	8.5	3.2	11.1	3.7
Coefficient of Variation	104%	122%	46%	30%	59%	41%
Range	9	75	29	8	35	12
Minimum	0.4	0.3	1.1	7.1	1.7	2.0
Maximum	9	75	30	15	37	14
N	9	9	9	9	9	9

Figure F.5.

VASOS Scores at Quarterly Monitoring Sites



Note: Possible Virginia Save Our Streams (VASOS) benthic community scores range from 0 (worst) to 14 (best).

Table F.7. Summary of Seasonal Data - VASOS Score

Indicator	Site					
	Site 6	Site 13	Site 15	Site 16	Site 19	Site 25
Mean	7.5	7.8	10.8	6.3	6.2	9.0
Median	8.0	8.0	11.0	6.0	6.0	9.0
Standard Deviation	1.8	1.4	1.3	1.6	1.1	2.4
Coefficient of Variation	23%	18%	12%	25%	18%	27%
Range	5	5	3	4	3	6
Minimum	5	5	9	5	5	6
Maximum	10	10	12	9	8	12
N	6	9	9	9	9	9